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AUGUST, 1927

The Shift in Infrared Reflection Maxima with Temperature — A. H. PFUND 69

Absorption Spectra of Mercury, Cadmium, and Zinc at High Pressure — F. L. MOHLER AND H. R. MOORE 74

Correction of a Prevalent Error in Regard to the Data on Photometric Sensibility as a Function of Wave Length at Low Brightness — IRWIN G. PRIEST 82

INSTRUMENT SECTION

The Alteration of Resistance, Inductance, and Capacity by Means of Coupled Amplifiers — CHARLES BAYNE AIKEN 85

A Photoelectric Process of Halftone Negative Making Applicable over Telephone Lines — HERBERT E. IVES 96

Some Properties of a Hot Wire Microphone — ORIN TUGMAN 110

A Compact Color Mixer — J. M. MCGINNIS AND D. S. PISTON 117

Laboratory Apparatus for the Electrolytic Preparation of Oxygen and of Ozone — OLIVER R. WULF 119

Reviews — 116

Notes — 84, 124

Index to Advertisers — Cover III

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THE SHIFT OF INFRARED REFLECTION MAXIMA WITH TEMPERATURE

By A. H. Pfund

The work of Rubens and others on selective reflection in the infrared has taken on a new significance in the light of modern theories of crystal lattices and specific heats of solids. In these theories a rôle of great importance is assigned to certain vibrators possessing definite "free periods." It seemed of interest, therefore, to investigate whether or not the frequencies of these vibrators remained constant or if they were affected by a rise in temperature.

From the very outset it was recognized that the investigation of such simple crystals as rock salt and sylvite should yield results which would be of greatest immediate value. In view, however, of the very formidable experimental difficulties encountered in the study of radiations having a wave length of 50 μ or greater, it was deemed expedient to carry out a preliminary investigation so as to determine whether or not the effect in question exists. For this reason the behavior of calcite, fused quartz and glass was studied in the easily accessible region; 6 to 10 μ.

The apparatus used consisted of an infrared spectrometer with mirrors of 30 cm focal length, and a rock-salt prism mounted according to Wadsworth. A vacuum thermopile[1] and a Leeds and Northrup high-sensitivity d'Arsonval galvanometer were employed for actual measurements. The mode of mounting the reflecting surface in front of the primary slit S_1 of the spectrometer is shown in Fig. 1. Here, N is a Nernst lamp whose radiations are first reflected from the polished

[1] Pfund, Phys. ZS., *13*, p. 870; 1912.

surface of the material A to be studied, and are then focused on the slit of the spectrometer slit S_1 by means of the concave mirror M. The shutter is introduced at T, thus cutting off only the radiation reflected, but not the superposed emission from the hot reflector. So as to insure a fairly uniform temperature distribution over the reflecting surface,

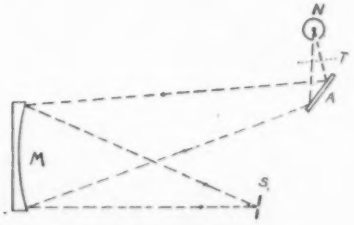

FIG. 1. *Infrared spectrometer.*

the reflector was mounted in a metallic frame B, Fig. 2, which could be heated by a blast lamp F or by means of a small electric furnace. Since preliminary tests showed that, at the same temperature, both methods of heating led to the same results, the blast lamp was used most generally since its use made possible the employment of large angles of incidence more readily than did the tubular electric furnace.

The surface temperature of the heated reflector was measured by means of a thin-wired platinum, platinum-rhodium thermocouple

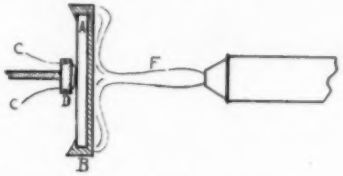

FIG. 2. *Reflector and couple mounting.*

whose junction was hammered out thin. The mode of mounting is shown in Fig. 2. The thermocouple C was attached to a circular disk of asbestos D about 8 mm in diameter. This disk, which approached the reflecting surface to within 1 mm, served the purpose of preventing heat-losses to the air without causing a general temperature rise over the entire reflecting surface. As shown in the illustration, the junction of the thermocouple was pressed firmly against the surface of the reflector.

In order to bring out the effect sought after as pronouncedly as possible, advantage was taken of the work of Gorton,[2] which showed that reflection maxima becomes very pronounced at large angles of incidence. In the present work the magnitude of the angle of incidence

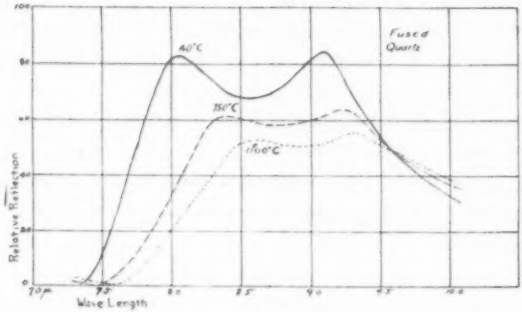

FIG. 3.

to be used was limited by the area of the reflectors. The angle chosen was 60°. The Nernst lamp was operated on a storage battery, and, as a result, the emitted radiation remained constant over long intervals of time. Therefore, after a complete set of data for the heated reflector

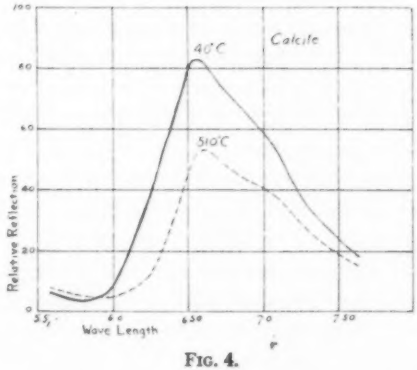

FIG. 4.

had been recorded, a silver mirror was mounted in place of the reflector and a further series of measurements, covering the same spectral range was recorded. Because of the fact that the reflector was held in the same position, the results obtained for the "cold" and "hot" reflector

[2] Gorton, A. F., Phys. Rev., 7, p. 67; 1916

are strictly comparable. Since, however, an exact replacement by the silver mirror was difficult, and since the values of absolute reflecting power were not of immediate interest, it was decided to plot the quantity "relative reflection" rather than "true reflecting power." After each heating, the reflection curve for the cold reflector was re-determined so as to make certain that no permanent change had been brought about in the reflector. As a matter of fact, no such permanent change was ever detected.

The curves obtained are shown in Figs. 3, 4 and 5. The most striking features revealed by these curves are:

1) A shift of the reflection maxima toward longer wave lengths with rise in temperature. 2) A progressive decrease in reflecting power with rise in temperature.

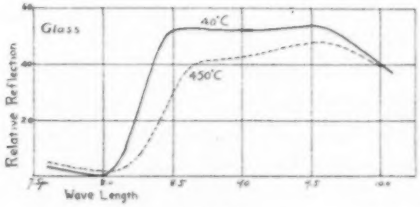

FIG. 5.

This decrease is exhibited by all of the substances studied. While the fused quartz and calcite reflectors remained rigid at all temperatures reached, the glass reflector had become sufficiently soft at 450°C to show the indentation mark left by the thermocouple which had been pressed against the hot surface. The actual shift of the reflection maxima is comparatively large for the amorphous reflectors (glass and fused quartz) but is slight for the crystalline reflector (calcite).

Since the phenomena of reflection, absorption and emission are intimately related, evidence for the effect in question was sought in earlier work. Anderson[3] found no shift in the sharp absorption bands of neodymium and erbium salts when heated to redness. Furthermore, Coblentz[4] has examined the emission spectra of a variety of substances formed into cylinders and heated by sending a current through them. It was found that the emission spectrum was characterized by sharp bands in the infrared. With temperature rise the well-known shift of the energy maximum toward shorter wave lengths ensued, but the wave

[3] Anderson, J. A., Astrophys. J., *26*, p. 73; 1907.
[4] Coblentz, W. W., Publ. Carnegie Inst., p. 93; 1908.

lengths of the sharp emission maxima remained fixed. The evidence, therefore, seems to be again an actual change of the periods of oscillation of the vibrators when the temperature is raised. To account for the shift toward greater wave lengths, observed in the present work, it was suggested by my colleague, Professor K. F. Herzfeld, that a reflection maximum might, in reality, be made up of a complex of bands which, while remaining unaffected in wave length, experience a change in intensity with rise in temperature. A phenomenon of this type has actually been observed by E. L. Nichols,[5] who found that zinc oxide, when heated, emits a series of bands of unvarying wave lengths. With an increase in temperature the bands of shorter wave length decrease in intensity while those of greater wave length grow relatively more intense. The resultant effect is an apparent shift of the emission maximum toward longer wave lengths.

In order to prove whether or not the observed shift of infrared reflection maxima may be explained in a similar manner, it will be necessary to investigate the "fine structure" of these reflection maxima by means of an echelette grating. This, it is hoped, will be done in the near future.

THE JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MARYLAND
JUNE, 1927.

[5] Nichols, E. L., J.O.S.A. & R.S.I., *13*, p. 661; 1926

ABSORPTION SPECTRA OF MERCURY, CADMIUM AND ZINC AT HIGH PRESSURE*

By F. L. Mohler and H. R. Moore

ABSTRACT

Absorption spectra of mercury, cadmium, and zinc vapors have been photographed with a quartz spectrograph using absorption cells containing vapor at pressures ranging up to several atmospheres.

The spectra are characterized by wide regions of continuous absorption and series of flutings and diffuse bands. Some of these have been previously observed in emission.

The flutings may be interpreted as poorly resolved band systems of diatomic molecules in which the excited electronic state is much more stable than the normal state. It is possible to account for the long duration of fluorescence by assuming that first the molecule is raised to a high vibration state by absorption and that consequently by a collision of the second kind it drops to a low vibration state having a very small emission probability.

It is generally recognized that metal vapors are not purely monatomic for the spectra of dense vapors show features characteristic of molecules. The fluted fluorescent spectra of the alkalies are the best example. These have been sufficiently analyzed to clearly indicate that they originate from diatomic molecules such as Na_2, K_2 and NaK.[1] Of the second group metals mercury has been most studied. The dense vapor shows regions of continuous absorption and emission but no fine structure that has been accurately analyzed. The authors have obtained absorption spectra of Hg, Cd, and Zn with pressures ranging to several atmospheres which show many features that have not been described before.

EXPERIMENTAL PROCEDURE

The source of radiation was a water-cooled discharge tube containing hydrogen at about 1.4 mm pressure. It was operated by a 5000 volt, 3 KW transformer, and gave a continuous spectrum which could be photographed from 3600 to 2100A in about a minute. Absorption cells were of quartz tubing with flat end plates and varied in length from 20 to 40 cm. An excess of metal was distilled into the tube in vacuo and it was then sealed off and heated in an electric tube furnace. In most cases the metal was in a side tube that could be heated independently and this was maintained at a lower temperature than the furnace. The values here given for vapor pressures of

* Published with the approval of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[1] Smith, Proc. Roy. Soc., *106*A, p. 400; 1924.

zinc and cadmium serve merely to indicate the magnitudes involved. Spectra were photographed with a Hilger E_2 quartz spectrograph. The use of a bromine cell in the path of the light improved the spectrograms by cutting out strong radiation longer than 3600A. This reduced fogging by light scattered within the spectrograph. The flutings and broad bands characteristic of these dense vapors could not be measured with precision and wave lengths are only given to the nearest angstrom except where repeated observations have been averaged.

OBSERVATIONS

Mercury. R. W. Wood[2] and several others have studied the mercury absorption spectrum under comparable conditions. Since the completion of this work a note by Lord Rayleigh[3] has appeared describing all the features found by the authors. Fig. 1 and Table 1 show the

Table 1. *Mercury absorption bands*

Band system	λ	ν	Δν	Intensity	Description
I	2345	42631	119	10	Diffuse bands fusing together at high pressure.
	2339	42740	92	5	
	2334	42832		2	
II	2932	34096	129		Wide flutings with optimum visibility near the middle of the series. They become clearer with increased pressure.
	2921	34225	141		
	2909	34366	130		
	2898	34496	144		
	2886	34640	120		
	2876	34760	122		
	2866	34882	109		
	2857	34991	136		
	2846	35127	136		
	2835	35263	112		
	2826	35375	101		
	2818	35476	101		
	2810	35577	114		
	2801	35691	89		
	2794	35780	103		
	2786	35883	104		
	2778	35987	77		
	2772	36064			

bands. λ2537, $1^1S - 2^3P_1$ appears near 85°C (.1mm). At 180°C (9 mm) the band at 2540A is seen and it is distinctly separated from 2537.

[2] Wood, Astrophys. J., *26*, p. 41; 1907.
[3] Rayleigh, Nature, *119*, p. 778; 1927.

With increased pressure (50 mm) 2540 fuses with 2537 but with further increase in pressure widens only on the red. Above 370°C (1100 mm) flutings (band system II) appear near the red edge of the continuous absorption and at 420°C (2100 mm) these flutings extend from 2770A to 2930A. At 256°C (90 mm) the bands at 2345A appear. These bands fuse together and widen only on the violet side with increasing pressure.

We made a series of exposures with the mercury in a side tube which was maintained at 380°C, giving a pressure of about 1200 mm while the temperature of the absorption cell was varied between this temperature and about 900°C. There was no noticeable change in the absorption spectrum though the green fluorescence which was strong at the lower temperature disappeared completely when the vapor was strongly superheated. This destruction of the fluorescence has been noted by many observers but our results do not support a commonly accepted explanation that the molecules responsible for the fluorescence are destroyed. Franck and Grotrian[4] have indeed shown that at a much lower pressure (20 mm) the absorption band at 2450A can be destroyed by superheating, but on the basis of their figures the effect would be negligible at 1200 mm. Recent results of Lord Rayleigh[5] show that the effect of temperature on the emission spectrum is much more complicated than it was formerly assumed to be.

Cadmium. Wood and Guthrie[6] have observed the absorption of cadmium at intermediate pressures while Dobbie and Fox[7] have published observations in the visible and near ultra-violet at high pressure. We did not find any of the bands listed by the latter. Impurities were a source of some difficulty and one carelessly filled tube showed a very strong band system degraded to the red with the strongest head at 2674A. We did not identify the source of these bands.

The line at 2288A, 1^1S-2^1P, is strong at 180°C (.0001 mm) and begins to widen at .3 mm. It gradually spreads over a wide range reaching 2212A at 600°C (80 mm), 2537A at 200 mm, and 2800A at 650 mm. 3261, $1^1S-2^3P_1$ appears at 360°C (.3 mm) and begins to widen at 800°C (1100 mm). Its width is roughly 77A at 1900 mm, 100A at 2700 mm, and 122A at 3400 mm. Table 2 lists the bands observed, and Fig. 1 includes some typical spectrograms.

[4] Franck and Grotrian, ZS. f. Tech. Phys., *3*, p. 194; 1922.
[5] Lord Rayleigh, Proc. Roy Soc., A*114*, p. 620; 1927.
[6] Wood and Guthrie, Astrophys. J., *29*, p. 211; 1909.
[7] Dobbie and Fox, Proc. Roy. Soc., *98*A, p. 147; 1921.

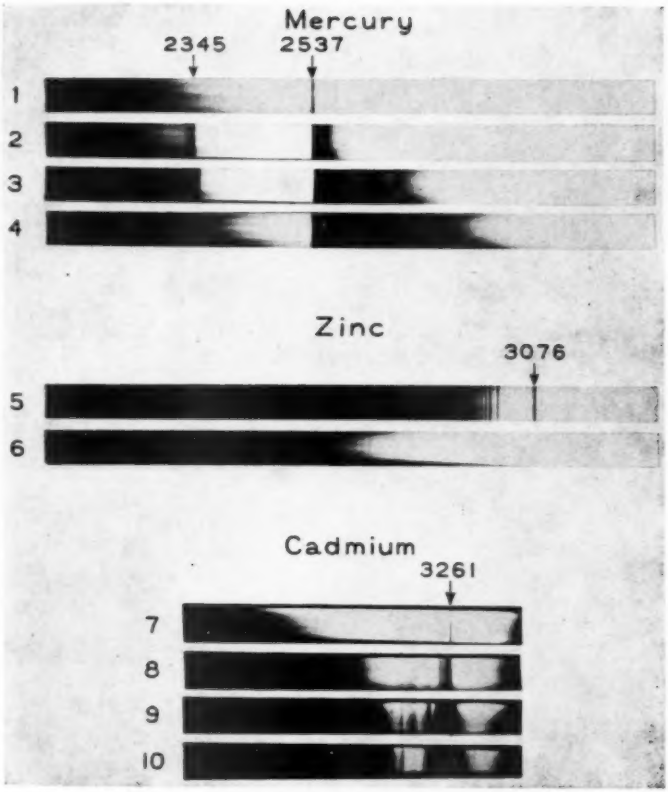

FIG. 1. *Absorption Spectra. Mercury 1, 22 mm; 2, 375 mm; 3, 1133; 4, 2120 mm. Zinc 5, 2300 mm 6, 730 mm. Cadmium 7, 235 mm; 8, 850 mm; 9, 1500 mm; 10, 3100 mm.*

Table 2. *Cadmium absorption bands*

Band system	λ	ν	Δν	Intensity	Description
I	2212	45194			Wide structureless band observed near 600°C (80 mm).
II	2781	35948	182		Wide flutings with optimum visibility near the middle of the series fading out at each end Appears between 630°C (130 mm) and 730°C (600 mm).
	2767	36130	144		
	2756	36274	145		
	2745	36419	120		
	2736	36539	134		
	2726	36673	121		
	2717	36794	109		
	2709	36903	109		
	2701	37012	96		
	2694	37108	97		
	2687	37205	94		
	2680	37302	98		
	2673	37400	98		
	2666	37498	99		
	2659	37597	85		
	2653	37682			
III	3071.2	32551	60	4	Appears above 700°C (400. mm) and is best at high pressure.
	3065.6	32611	74	2	
	3058.6	32685	68	1	
	3052.3	32753	67	1	
	3046.0	32820	65	1	
	3040.0	32885	60	1	
	3034.5	32945	63	0	
	3028.7	33008	62	0	
	3023	33070		0	
IV	3104	32207	83	1)	Appears above 760°C (700 mm) and is resolved into separate bands at the highest pressure.
	3096	32290	74	1)	
	3089	32364	63	1)	
	3083	32427		0	
V	3177.3	31464	70	8	Appears above 680°C (200 mm) and is best at high pressure.
	3170.3	31534	95	4	
	3160.7	31629	112	2	
	3149.6	31741	87	1	
	3141	31828		0	
VI	3249	30769	75	4	Appears as narrow bands at 640°C (170 mm). These fuse together at high pressure. Impurity?
	3241.2	30844	90	6	
	3231.8	30934	91	8	
	3222.3	31025		12	
VII	3310	30203	91	1	Only observed on one exposure at 815°C (1400 mm).
	3300	30294	102	1	
	3289	30396		0	

Zinc. The line at 2139A, 1^1S-2^1P is widened out to 2300A at 830°C (350 mm) and to 2800A at 1000°C (1800 mm). 3076, $1^1S-2^1P_1$ appears at 490°C (1 mm) and is only a few angstroms wide at 2200 mm. Table 3 lists the bands.

Mixtures. A number of spectrograms of vapor mixtures, Cd and Hg, Cd and Zn, Zn and Hg showed no very conspicuous features characteristic of the mixtures. Zn and Cd showed a broad structureless band near 2500A while Cd and Hg showed faint flutings between 2400 and 2500A. Most of the band systems appeared in the same relative intensity as in the pure vapor but group VI (Table 2) of cadmium was exceptional. It was relatively strong in the Cd Zn mixture and absent in the Cd Hg mixture. This suggests that it may belong to some impurity.

TABLE 3. *Zinc absorption bands*

Band system	λ	ν	Δν	Intensity	Description
I	2636	37925	202		Wide flutings with optimum visibility near the middle of the series.
	2622	38127	205		
	2608	38332	207		
	2594	38539	179		Appear between 850°C (400 mm) and 950°C (1150 mm).
	2582	38718	166		
	2571	38884	182		
	2559	39066	122		
	2551	39188			
II	2990	33435		0	Narrow bands appear above 800°C (200 mm) and are best at the highest pressure.
	2976	33592		1	
	2957.2	33806		6	
	2942.7	33972		3	
	2934.1	34072		8	
	2922.5	34207		2	
	2911.6	34335		1	
	2902	34449		0	
III	3050			1	A broad structureless band appearing above 950°C (1150 mm).

INTERPRETATION OF RESULTS

A striking feature of the spectra of the three elements is the long series of diffuse flutings II of mercury, II of cadmium and I of zinc. In mercury and cadmium vapors a similar and perhaps identical spectrum has been observed in emission. Lord Rayleigh[6] gives photographs and measurements of the flutings as excited by a low current

discharge in dense mercury vapor. He records 33 flutings extending from 2697 to 3055A, and in the range of our measurements they are nearly but not exactly coincident with the absorption bands. He also observed the 2345 bands in emission. Vander Lingen[8] and Kapuscinski[9] have published photographs of the fluorescent spectrum of cadmium which show a series of flutings that are apparently identical with our cadmium II absorption bands.

These flutings bear little resemblance to the familiar types of band series yet it can be shown that they may well be partially resolved band series of molecules Hg_2 and Cd_2. The rotational fine structure of Hg_2 will probably be too fine to be resolved by the most powerful spectroscope. Assuming that the nuclear separation is twice the atomic radius, we compute that lines of the rotational fine structure will fall at intervals of .002A in this spectrum range. Possibly the far infrared emission bands observed by Rubens and v. Baeyer[10] at 324 and 210μ are the vibration spectrum of Hg_2. If so the interval between vibration states of the normal electronic state is about 17 cm^{-1}. Franck and Grotrian[4] and later Koernicke[11] have computed the work of dissociation of Hg_2 from measurements of the fading of the 2540 band with superheating. They give 1.0 and 1.4 kg cal respectively, from which it follows that the vibration states of the normal electronic state will extend over a frequency range of about 400 cm^{-1}.[12] We would interpret the series of flutings as the band system resulting from molecules going from a low vibration state in the normal electronic state to successive vibration states associated with some higher electronic state. The frequency range and intervals of the flutings are determined primarily by the excited vibration states. It is evident that the stability of the molecule is very much greater in this excited state than in the normal state. The mean frequency interval is 130 cm^{-1} as compared with 17 for the normal state; the range is greater than 6500 cm^{-1} (see following) as compared with 400 cm^{-1}. Because of this great difference the vibration structure will not appear degraded to the violet as in cases where ν_0 values are comparable but the separate vibration transitions will actually shade off to the red. Thus the band resulting from the transition from $n=1$ of the normal electronic state to $n=n'$ in the

[8] Vander Lingen, ZS. f. Phys., *6*, p. 403; 1921.
[9] Kapuscinski, ZS. f. Phys., *41*, p. 214; 1927.
[10] Rubens and v. Baeyer, Phil. Mag., *21*, p. 689; 1911.
[11] Koernicke, ZS. f. Phys., *33*, p. 219; 1925.
[12] Birge and Sponer, Phys. Rev., *28*, p. 259; 1926.

excited state will fall adjacent to the band from $n=0$ to $n=n'$ and on the red side. In the usual case it falls near the violet side of the band $n=0$ to $n=n'-1$. While the unresolved group of bands degrades to the red the separate bands presumably degrade to the violet. This accounts for the diffuse character of the bands and also for the fact that the emission spectrum shows the same series of flutings with the maximum slightly displaced. The great difference in stability is consistent with the fact that there is no well defined red limit to the series of bands, for transitions to high values of n' are most probable.[13]

Our results show that the intervals between flutings decrease with increasing frequency, and Rayleigh[3] on the basis of a much longer series estimates the limit as being slightly on the violet side of 2537. This limit gives the energy required to dissociate Hg_2, leaving one of the atoms in some excited state. If 2^3P_1 is this final state then on the basis of 1.2 kg cal (420 cm^{-1}) as the work of dissociation of normal Hg_2 the computed limit is at 2510A which is consistent with Rayleigh's description. The total extent of the band system is greater than 6500 cm^{-1} which sets a lower limit of 0.8 volts (18 kg cal) for the work of dissociation of the excited molecule.

The 2345 band series has been correlated with the 2^3P_2 state of the atom.[4] If this is true the limit of the band series is near 2250A or 44,440 cm^{-1}. This band group has an entirely different intensity distribution which suggests that the transition $n=0$ to $n'=0$ is most probable. Assuming that 2345A is the $n'=0$ band, the work of dissociation of this excited state is .22 volts (5 kg cal).

From a comparison of the molecular absorption at equal pressures it is apparent that Cd_2 and Zn_2 have a stability comparable with Hg_2. The long series of flutings II of cadmium and I of zinc must be related to the 2^1P state of the atom and this excited state must have a very high stability comparable with Hg_2 in the 2^3P_1 state. There are two band systems, III and V of cadmium, which resemble the 2345 group of mercury. Cd V may be associated with the 2^3P_2 state of the atom. If so the convergence will be at a higher frequency than 31,827 cm^{-1} and the work of dissociation of this excited state is 0.04 volts greater than for the normal electronic state.

We conclude that the flutings and diffuse band series in absorption spectra of dense vapors may be interpreted as poorly resolved absorp-

[13] Franck, Trans. Faraday Soc., "Photo Chemical Reactions," p. 536; 1925 and Condon, Phys. Rev., *28* p. 1182; 1926.

tion band systems. They differ from the usual diatomic band system chiefly in the large difference in stability of the normal and excited states. This interpretation confirms the prediction of Franck and Grotrian[14] that there will be a much greater affinity between an excited and normal atom than between two normal atoms.

Mercury fluorescence. Mercury fluorescence, particularly the visible green band, has attracted attention because of several abnormal properties. The duration of fluorescence after excitation is very long,[5] $1.8 \cdot 10^{-3}$ sec half period, and the visible part of the spectrum may be extinguished by heating. The long life has been explained by the hypothesis that the Hg_2 molecule falls into a metastable excited state but it is difficult to see how a diatomic molecule could have any truly metastable state. One can see, however, that a band system such as II of Hg may have states of very long life. Hg_2 molecules at low pressure would absorb radiation and radiate in a period determined by the absorption coefficient (in general a short period). Because of the satbility mentioned above, the excited state involved would in general have a high vibration quantum number.[12] But the fluoresecnce is generally observed with a total pressure so high that collisions will occur before radiation takes place. Some molecules will fall to low vibration states by collisions of the second kind and then will have a very long life as the absorption and emission probabilities are very low. In equilibrium conditions some molecules will radiate and some will return to high vibration states by collisions of the first kind. At low temperatures the radiation process will predominate and at high temperatures the molecules will revert to a state of short life. It is possible that this accounts for some of the peculiar properties of the visible fluorescence.

Bureau of Standards,
Washington, D. C.
June 24, 1927.

[14] Franck and Grotrian, ZS. f. Phys., *4*, p. 301; 1921.

CORRECTION OF A PREVALENT ERROR IN REGARD TO THE DATA ON PHOTOMETRIC SENSIBILITY AS A FUNCTION OF WAVE LENGTH AT LOW BRIGHTNESS*

By Irwin G. Priest

This note ventures to correct an error which seems to be in course of extensive propagation in the literature of visual psychophysics. This error is in regard to the departures from Weber's Law considered as dependent upon wave length at low brightness (photometric sensibility).

The error was apparently first introduced into the literature in the second edition of Helmholtz' "Physiologischen Optik," Leipzig, 1896, pp. 402–403. From this source it was copied by Peddie.[1] Parsons, in a book which is, in general, a very valuable and useful reference work, has in turn copied the error from Peddie, citing only Peddie for authority, without any reference to either Helmholtz or the original authorities for the data.[2] In a more recent paper Peddie[3] again repeats the same error, apparently not having noticed that attention had, in the interim, been directed[4] to his previous mistaken interpretation of these data.

Seeing how it continues to gain currency, it may serve a useful purpose to expose this error again before it becomes more firmly entrenched by repeated copying.

The original data are due to Koenig and Brodhun.[5] The figure reproduced herewith is a facsimile of Fig. 1 in the original paper.[6] The abscissas represent the magnitude of the stimulus (log scale).

* Published with the approval of the Director of the Bureau of Standards, U. S. Department of Commerce.

[1] W. Peddie, "Colour Vision," London, page 45; 1922.

[2] J. H. Parsons, "Introduction to the Study of Colour Vision," Second Edition, Cambridge, pp. 23–24; 1924. At another place in the same book (Fig. 20, p. 51), Parsons, following Nutting, gives the correct representation of the same data without noting the contradiction.

[3] W. Peddie, "The Mathematics of Colour Vision—," Trans. Optical Convention, p. 227; 1926.

[4] J.O.S.A. & R.S.I., 7, p. 1254; Dec. 1923.

[5] "Experimentelle Untersuchungen über die psycho-physische Fundamentalformel in Bezug auf den Gesichtssinn." Sitzungsber. der Akad. der Wissensch., Berlin, pp. 917–931; July 26, 1888. Also in Koenig's "Gesam. Abhand. zur Physiol. Optik," pp. 116–134; Leipzig 1903.

[6] Sitzungsber. der Akad. der Wissensch., p. 925; Berlin, July 26, 1888.

The ordinates represent the ratio of a "just perceptible difference" to the total stimulus. The branch of the curve marked "II" represents the relation for *longer* wave lengths (red and yellow) while the branch marked "III" represents it for the *shorter* wave lengths (blue).[7]

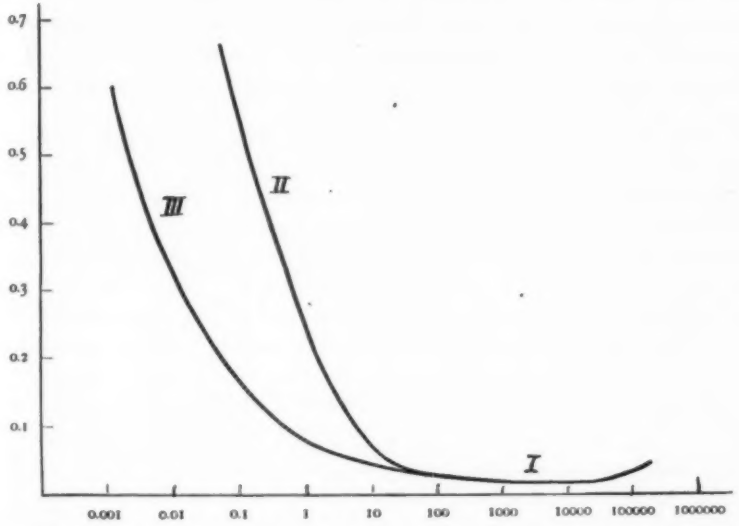

FIG. 1. *Copy of Fig. 1 from paper by Koenig and Brodhun, Sitzb., Berlin, July 26, 1888, p. 925.*

This same figure was reproduced on page 403, of the second edition of Helmholtz' "Physiologischen Optik" and has been reproduced in turn by Peddie and Parsons. The original error occurs in the following sentence on page 402 of the Helmholtz text: "Der Zweig I der Curve

[7] The following is quoted from the text describing this figure and immediately following it in the original paper:

In der vorstehenden Fig. 1 sind als Abscissen die Werthe von r im Maassstabe ihrer Logarithmen, hingegen die Werthe des Quotienten $\partial r : r$ selbst als Ordinaten schematisch eingetragen. Der Curvenzweig I entspricht den hier besprochenen hohen Intensitäten. Zwischen den Intensitäten 2000 und 20000 läuft die Curve horizontal d. h. $\partial r : r$ hat einen constanten Werth. Nach beiden Seiten hin findet dann eine Zunahme statt.

Hinsichtlich der niedrigeren Intensitäten zerfallen die sechs untersuchten Spectralregionen in zwei Gruppen, deren eine die Wellenlängen 670$\mu\mu$, 605$\mu\mu$ und 575$\mu\mu$, die andere die Wellenlängen 505$\mu\mu$, 470$\mu\mu$ und 430$\mu\mu$ enthält. Die Werthe von $\partial r : r$ sind für die erste Gruppe in dem Curvenzweig II, für die zweite in dem Curvenzweig III eingetragen. Die Curven steigen ständig mit abnehmendem Werthe von J (bez. r) und zwar ist die Zunahme von $\partial r : r$ bei der ersten Gruppe (II) viel stärker als bei der zweiten Gruppe (III).

bezieht sich auf die hohen Beleuchtungsstärken, II auf die blaue Hälfte des Spectrum, die Wellenlängen 505$\mu\mu$ bis 430$\mu\mu$ zusammenfassend, III auf die rothgelbe, zwischen den Wellenlängen 670$\mu\mu$ und 575$\mu\mu$." The error thus consisted in the mere oversight of interchanging the references to the curves II and III in the figure, so that II is erroneously said to refer to shorter wave lengths and III to longer wave lengths, whereas the converse of this was the original statement of Koenig and Brodhun. This is the error which has been copied by Peddie and Parsons in referring to the same figure.

That the error is a mere oversight in referring to the figure may be readily seen from inspection of the numerical data in the tabular form which follow on pp. 405–408 of the Helmholtz text. The error is readily discerned by one who is studying the subject and not merely copying in a mechanical manner.[8] There is no doubt about the actual facts.[9]

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
JUNE, 1927.

[8] I find that it is corrected in pencil in the Bureau of Standards Library copy of Helmholtz. This correction was probably made by Nutting who was studying the subject at the Bureau in 1906. Cf. Nutting, "Complete Form of Fechner's Law," Bull. of Bur. of Stands. *3*, pp. 59–64; 1907; and "Outlines of Applied Optics," pp. 124–126.

[9] New experimental data on photometric sensibility for red and blue taken under my direction at the Bureau of Standards by F. K. Harris, (unpublished data taken in 1924) are in accord with the original statement of Koenig and Brodhun.

Measurement of the reflecting power of metallic surfaces.—A method is described that permits the determination of the reflecting power of transparent metallic films for all those wave lengths that traverse quartz without much absorption. The intensity of light subjected to reflection on two films of the metal is compared photographically with that which has been reflected twice from the faces of a standard quartz prism of acute angle. The precision obtainable increases with the reflecting power. The error is of the order of about 1% for reflecting powers of 0.35, and less than 0.3% for reflecting powers of 0.65. The method is not useful for the measurement of reflecting powers less than 0.15. It can be used on polished opaque surfaces.—[M. Duffieux; Revue d'Optique, *5*, pp. 204–212; 1926.]

G. W. MOFFITT.

INSTRUMENT SECTION

THE ALTERATION OF RESISTANCE, INDUCTANCE AND CAPACITY BY MEANS OF RESISTANCE COUPLED AMPLIFIERS

By Charles Bayne Aiken

The reduction of the resistance of non-oscillating circuits by the use of vacuum tubes has been discussed by Bennett and Peters[1] and by Stratton[2] and these authors have pointed out a number of advantages which may be realized by employing regeneration in connection with various types of filter and other circuits. The schemes which they have discussed all depend on inductive feed-back and hence the negative resistances which can be introduced into a circuit by such methods are functions of the frequency. Stratton cites an example in which he completely eliminated a single frequency by means of a parallel resonant circuit, the resistance of which was reduced by regeneration. However, a change in the frequency of .1 cycle in 1000, or .01 of 1 per cent, upset the balance and resulted in the passage of a detectable current through the filter circuit. In many cases it is desirable to introduce a negative resistance which is at least approximately independent of frequency. This may be accomplished by the use of a resistance coupled amplifier, and in the present paper there is considered the utilization of such an amplifier in the problem of resistance neutralization.

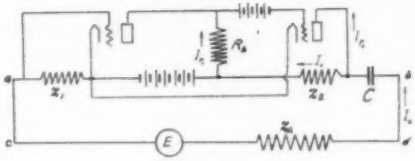

Fig. 1.

Suppose we desire to modify the effective series impedance of a circuit by a definite amount. This can be accomplished by introducing the arrangement shown in Fig. 1 between the points a and b. If I_0 is

[1] Resistance Neutralization, An Application of Thermionic Amplifier Circuits. Jour. A.I.E.E., *41*, p. 243; 1922.

[2] Complete Suppression of a Single Frequency by Means of Resonant Circuits and Regeneration. J.O.S.A. and R.S.I., *13*, p. 95; 1926.

the current through generator, then the total effective impedance of the closed circuit *acdb* is $Z_0 = E/I_0$. We proceed to derive an expression for $Z = Z_0 - Z_A$.

Writing down the Kirchoff equations for the circuit and neglecting the impedance of the blocking condenser C, we have:

$$E = Z_A I_0 + Z_2 I_2 + Z_1 I_0$$

$$\mu_2 e_{g2} = R_{P_2} I_{P_2} - Z_2 I_2$$

$$I_0 = I_2 + I_{P_2}$$

$$e_{g2} = -R_b I_{P_1} = -\frac{\mu_1 e_{g1} R_b}{R_b + R_{P_1}} = -\mu_1 \theta_1 e_{g1}$$

$$e_{g1} = -Z_1 I_0$$

The solution of these gives:

$$(1) \qquad Z = Z_0 - Z_A = \frac{E}{I_0} - Z_A = \frac{R_{P_2} Z_2}{R_{P_2} + Z_2} + Z_1 \left(1 - \frac{\mu_1 \mu_2 \theta_1 Z_2}{R_{P_2} + Z_2}\right)$$

Z is seen to be independent of E and Z_A and contains three terms, the first of which is merely the impedance of R_{P_2} and Z_2 in parallel, while the third contains the product $\mu_1\mu_2$ and may be a resistance, reactance, or complex impedance, depending upon the values assigned to Z_1 and Z_2.

If we substitute for Z_1 and Z_2 their complex forms, $Z_1 = R_1 + JX_1$ and $Z_2 = R_2 + JX_2$, there results

$$(2) \qquad Z = Z_1 + \frac{R_{P_2}^2 R_2 + R_{P_2} R_2^2 + R_{P_2} X_2^2 - \mu_1\mu_2\theta_1 \{R_1 R_2 R_{P_2} + R_1 R_2^2 - X_1 X_2 R_{P_2} + R_1 X_2^2\}}{(R_{P_2} + R_2)^2 + X_2^2}$$

$$+ j \frac{\{R_{P_2}^2 X_2 - \mu_1\mu_2\theta_1 (R_1 R_{P_2} X_2 + R_{P_2} R_2 X_1 + R_2^2 X_1 + X_1 X_2^2)\}}{(R_{P_2} + R_2)^2 + X_2^2}$$

We shall consider certain special cases, the first being that in which $Z_1 = R_1 + JO$, $Z_2 = R_2 + JO$.

$$Z = \theta_2 R_{P_2} + R_1 (1 - \mu_1\mu_2\theta_1\theta_2)$$

$$\theta_1 = \frac{R_b}{R_b + R_{P_1}} \qquad \theta_2 = \frac{R_2}{R_2 + R_{P_2}}$$

Z is a pure resistance and may be made positive, negative, or zero depending on the values given R_1 and R_2. For type 199 tubes μ is approximately six and if θ_1 and θ_2 are of the order of $\frac{3}{4}$, then we have:

$$Z = .75 R_{P_2} - 19 R_1$$

To test out the validity of these predictions, the part of the circuit between a and b, Fig. 1, was placed in series with an external resistance of 5000 ohms and the whole connected in one arm of an alternating current bridge. With R_1 set at zero $R_{P_2}R_2/(R_2+R_{P_2})$ was adjusted to a value of 10,500 ohms. UV 199 tubes were used. R_2 had a value of 48,200 ohms and R_b of 53,250 ohms. The blocking condenser C had a capacity of 2.5 mf. This condenser is necessary in order to keep the B battery current out of the external circuit. The total effective resistance R was measured for various values of R_1. The results of the run are shown

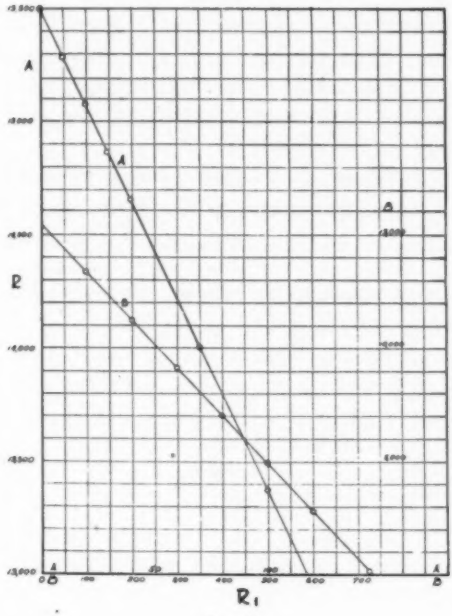

FIG. 2.

in Fig. 2. It will be noted that the relation between R and R_1 is perfectly linear and that the effective resistance was reduced from a total of 15,500 ohms to 170 ohms. For lower values of R the harmonics became excessive due to overloading of the tubes and the operation of the device became unsatisfactory. From the graph we find that $\Delta R/\Delta R_1 = -21.1$. Hence, by virtue of (1) we have

$$\mu_1\mu_2\theta_1\theta_2 = 22.1$$

which is of the same order of magnitude as the value suggested above.

The circuit did not act as a pure resistance but showed a small reactive component which was negative under certain conditions and positive under others. This component was due to the condenser C and to phase shifts in the tube circuits. It was quite small in all cases and will not be further considered.

The proper functioning of this network depends upon linear amplification. If the tubes are overloaded, the voltage introduced into the circuit by the passage of the plate current through Z_2 is no longer proportional to the voltage drop across Z_1, and the relation (1) ceases to be valid. In the procedure mentioned above, the current I_0 increased considerably as R was decreased. For low values of R the harmonics became prominent and finally increased to such an extent as to make the bridge balance poor. However, it is evident that the overloading was not very serious, since the plot of R against R_1 is linear throughout its full extent.

It will be noted that in Fig. 1 a high voltage grid battery is used with the second tube rather than a grid condenser and leak. This does away with blocking of the amplifier and makes for greater stability of operation.

In order to get a quantitative idea of the effect of overloading, the voltage supplied to the bridge was varied and the current I_0 measured with a milliameter. R_1 was kept at a fixed value and the variations in R due to increase in line current were noted. The results are given in Table 1 for three values of R_1. It will be noted that the changes in R

TABLE 1.

$R_1=500$ ohms		$R_1=600$ ohms		$R_1=700$ ohms	
I_0	R	I_0	R	I_0	R
.02 ma.	4952 ohms	.10 ma.	2834 ohms	.20 ma.	723 ohms
.06	4968	.18	2860	.25	735
.10	4984	.25	2914	.30	745
.15	5006	.30	2962	.50	790
.19	5027	.34	2980	.75	903
				.85	980
				1.0	1088

are greater, the greater the value of R_1 and the larger the line current. When the line current is small, equation (1) is accurately obeyed. In cases where a decrease in resistance is desired in the neighborhood of a null setting, this method of neutralization should be quite satisfactory.

If tubes of higher capacity are used, larger currents than those here recorded may be used without failure of the linear amplification characteristics.

One of the chief advantages of this system of resistance neutralization has already been mentioned,—it is practically independent of frequency. In Table 2 is shown a series of values of R measured at different frequencies. These are very constant except for a slight increase at the higher frequencies.

TABLE 2.

f	R	f	R
590	2826 ohms	1125	2831 ohms
680	2826	1200	2834
740	2824	1300	2836
780	2825	1430	2838
870	2824	1620	2840
956	2826	1900	2854
1020	2828		

At frequent intervals throughout the various runs described above, the value of the total resistance of 15,500 ohms which obtained with R_1 set at zero, was checked, and any variations were remedied by adjusting the filament current. These variations were small, seldom amounting to more than ten ohms. If the external resistance is of the order of several thousand ohms and it is desired to reduce the total resistance to say, ten per cent of this value then these variations will be of no great importance. If an attempt is made to reduce the total resistance to a value considerably smaller than this then the changes in the plate circuit resistance become more important and tend to cause instability. However it has been found experimentally that troubles due to over loading of the tubes make themselves evident before any instability of the above type becomes serious.

If $Z_1 = R_1 + jX_1$ and $Z_2 = R_2 + jX_2$, equation (1) then becomes

$$Z = \theta_2 R_{P_2} + Z_1(1 - \mu_1\mu_2\theta_1\theta_2)$$

or as above

$$Z = \theta_2 R_{P_2} - 21Z_1$$

By adjusting the resistance component of Z_1 we can make R take on any desired value within wide limits and this value will be inde-

pendent of frequency. The introduction of a reactive component in Z_1 will result in a total reactance of twenty-one times the value of X_1 and of opposite sign. Thus we may introduce into a circuit a positive reactance that will vary with frequency in the same manner as a capacity reactance or a negative reactance that will behave like an inductive reactance. By this means it would be possible to "tune" a circuit for all frequencies, that is, annul its reactance and there will be no tendency to oscillation, since we should use a condenser to annul a capacity reactance. If a condenser is used in Z_1, it will be necessary to shunt it with a high resistance grid leak in order to prevent blocking of the first tube.

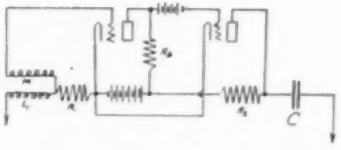

FIG. 3.

By a slight modification of the circuit it is possible to introduce a positive reactance of large value which will vary directly as the frequency. This may be done by using a mutual inductance in Z_1 as indicated in Fig. 3. The expression for Z in this case is:

$$Z=\theta_2 R_{P_1}+R_1(1-\mu_1\mu_2\theta_1\theta_2)+j\omega(L_1\pm\mu_1\mu_2\theta_1\theta_2 M)$$

If there are available two coils, each of inductance L_1, then by connecting them in series we can obtain a total inductance of $L=2(L_1+M)=2L_1(1+k)$, in which k is the coefficient of coupling. On the other hand, by using these two coils in the circuit of Fig. 3 we can get a total effective inductance of

$$L=L_1+\mu_1\mu_2\theta_1\theta_2 M=L_1(1+\mu_1\mu_2\theta_1\theta_2 k)=L_1(1+22k)$$

the last equality being true for the set up used in the above experiments on resistance reduction. The total inductance will be the same for the two cases when $1+22k=2(1+k)$ or $k=1/20$. For all greater values of k a greater inductance will be obtained by using the vacuum tube device.

Since the sign of capacity coupling cannot be reversed, we cannot increase the effective value of a capacity but can merely change the sign of an inductive reactance as described above.

If there are n stages of resistance coupled amplification, the expression for Z will be:

$$Z=\theta_n R_{P_n}+(1-[-1]^n\mu_1\cdots\mu_n\theta_1\cdots\theta_n)Z_1$$

If n is odd, we may multiply the reactive component of Z_1 by a large factor without changing its sign, but the resistance component will be multiplied by the same factor.

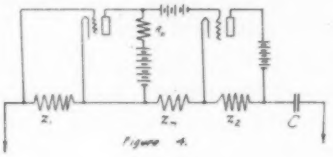

FIG. 4.

In Fig. 4 is shown a circuit which does not impose these restrictions on the alteration of the effective capacity reactance. The equation of this circuit is:

$$Z=\frac{Z_2R_{P_2}}{R_{P_2}+Z_2}+Z_m+Z_1\left(1-\frac{\mu_1\mu_2\theta_1Z_2}{R_{P_2}+Z_2}\right)+\frac{Z_m\mu_2Z_2}{Z_2+R_{P_2}}$$

If Z_2 is a pure resistance, this becomes:

$$Z=\theta_2R_{P_2}+Z_m+Z_1(1-\mu_1\mu_2\theta_1\theta_2)+Z_m\mu_2\theta_2$$

By making Z_1 a resistance of the proper value we can annul the resistance of the external circuit and that of Z_m and the term $Z_m\theta_2\mu_2$ as well. Then, by giving Z_m a reactive component X_m we introduce into the circuit a total reactance of $X_m(1+\mu_2\theta_2)$.

The chief objection to the schemes discussed above is the introduction of the term $Z_2R_{P_2}/(Z_2+R_{P_2})$ which is necessarily rather large, since Z_2 must be larger than the plate resistance of the tube if we are to secure a large multiplying factor for Z_1. The lower limit of Z_2 depends upon the alterations in X and R which are desired. If we are to have R negative and X of sign opposite to X_1, then the inequality $\mu_1\mu_2\theta_1R_2/(R_2+R_{P_2})>1$ must be satisfied. This sets a lower limit to R_2 which is of the order of 500 ohms. However, if we wish to obtain a large negative value of R, then R_2 must be much larger than this, and for efficient operation should be several times as large as R_{P_2}. In the neutralization of large resistances this term may not be a serious factor, but when a small resistance is to be anulled other means must be sought,

since the variations in the plate resistance of the second tube due to changes in the voltages of the various batteries in the circuit may be large compared with the external resistance for which it is desired to compensate. Inductive feed-back schemes are well adapted to the neutralization of small resistances provided the frequency is held constant or in cases in which the neutralization is desired for a critical frequency only. We shall now consider a scheme for the reduction of small resistance which is less critical with respect to frequency than those depending on inductive feed back.

Let us suppose that in the circuit of Fig. 1, $Z_1=X_1$, $Z_2=X_2$, the resistance components of these impedances being negligible. Furthermore, let us suppose that X_2 is negligible in comparison with R_{P_2}. Equation (1) then becomes:

$$Z=jX_1+jX_2+\mu_1\mu_2\theta_1\frac{X_1X_1}{R_{P_2}}$$

If $X_1=L_1\omega$ and $X_2=-1/\omega C_2$ then the last term will not contain the frequency

$$Z=j\left(L_1\omega-\frac{1}{\omega C_2}\right)-\frac{\mu_1\mu_2\theta_1}{R_{P_2}}\cdot\frac{L_1}{C_2}$$

Let

$$\frac{\mu_1\mu_2\theta_1}{R_{P_2}}=K \qquad \Omega=\frac{1}{(L_1C_2)^{1/2}}$$

$$X_{10}=L_1\Omega=\frac{1}{\Omega C_2}$$

$$\left(\omega L_1-\frac{1}{\omega C_2}\right)=(\Omega+\Delta\omega)L_1-\frac{1}{C_2}\left(\frac{1}{\Omega}-\frac{\Delta\omega}{\Omega^2}+\cdots\right)$$

$$=\Omega L_1-\frac{1}{\Omega C_2}+L_1\Delta\omega+\frac{\Delta\omega}{\Omega^2C_2}$$

$$=\frac{\Delta\omega}{\Omega}\left(L_1\Omega+\frac{1}{\Omega C_2}\right)=2X_{10}\frac{\Delta\omega}{\Omega}$$

I X_1 an X_2 are adjusted to the same absolute value at the operating frequency $\Omega/2\pi$ then $Z-KL_1/C_2-KX_{10}^2$ and at frequencies differing from Ω by the small amount $\Delta\omega$

$$Z=2jX_{10}\frac{\Delta\omega}{\Omega}-KX_{10}^2$$

The term KX_{10}^2 represents the negative resistance and is independent of frequency.

$$R = R_A - KX_{10}^2$$

If R is reduced to 10 per cent of R_A, then

$KX_{10}^2 = .9R_A$ and assuming $K = 2\times10^{-3}$, $X_{10} = 10(4.5R_A)^{1/2}$

Three cases give results as follows:

TABLE 3.

R_A	R	X_Δ	ρ
50	5	3.00	60.00
500	50	9.47	18.94
1000	100	113.40	13.40

X_Δ is the value of the total effective reactance of the circuit when the frequency differs from the resonant value by one per cent. ρ is the value of X_Δ expressed in terms of per cent of R.

$$\rho = 100\frac{X_\Delta}{.1R_A} = 100\frac{2X_{10}}{100}\cdot\frac{1}{.1R_A}$$

$$\rho = \frac{424}{(R_A)^{1/2}}$$

Hence the relative importance of the reactive term varies inversely as the square root of the external resistance.

The variation of reactance with frequency is very much smaller than in inductive feed back schemes while the resistance is constant provided R_{P_1} and R_{P_2} are constant. The variations in R_{P_2} cause variations of the same percentage value in the term KX_{10}^2 which term is of the same order of magnitude as the small resistance to be reduced. In the cases which have been previously discussed the variations occur in a term which is large and hence if the resistance R_A is small, the per cent variations of the total effective resistance of the circuit will be large.

Additional advantages may be realized, especially for resistances of the order of 1000 ohms, by employing the circuit of Fig. 3, replacing R_2 by a capacity C_2 and making M/L_1 as large as possible. We have:

$$Z = R_1 - \frac{\mu_1\mu_2\theta_1}{R_{P_2}}\cdot\frac{M}{C_2} + j\left[L_1\omega - \frac{1}{\omega C_2}\left(1 - \mu_1\mu_2\theta_1\frac{R_1}{R_{P_2}}\right)\right]$$

$$= R_1 - \frac{KM}{C_2} + j\left(L_1\omega - \frac{1}{\omega C_2'}\right) \qquad \text{Assuming } Z_2 << R_{P_2}$$

In which

$$C_2' = \frac{C_2}{1 - \frac{\mu_1 \mu_2 \theta_1 R_1}{R_{P1}}} = \frac{C_2}{1 - KR_1}$$

By making $C_2' > C_2$ and $L_1 < M$ we can reduce the relative importance of the reactive term. If C_2/C_2' is to be .2 or less there is not a wide range of choice of R_1. Assume $K = 2 \times 10^{-3}$ and $R_1 = 400$ ohms. Then $C_2/C_2' = .2$. In a manner similar to that employed above we find that

$$X = \left(L_1\omega - \frac{1}{\omega C_2'} \right) = 2X_{10}\frac{\Delta\omega}{\Omega'} = 2X_{20}'\frac{\Delta\omega}{\Omega'}$$

$$X_{10} = L_1\Omega' \qquad X_{20}' = \frac{1}{\Omega' C_2'} \qquad \Omega' = \frac{1}{(L_1 C_2')^{1/2}}$$

$$M\Omega' = X_{M0} = 2X_{10} = 2X_{20}' = \frac{2}{5}X_{20}$$

$$R = R_A + R_1 - \frac{5}{2}KX_{M0}^2$$

If R is to be reduced to 10 per cent of R_A then

$$\frac{5}{2}KX_{M0}^2 = 400 + .9R_A$$

$$X_{M0} = 10(800 + 1.8R_A)^{1/2}$$

$$X = X_{M0} \cdot \frac{\Delta\omega}{\Omega'}$$

In the following table are given the values of X_Δ and of ρ for the same values of R_A and R as have been considered above. For purposes of comparison the previous values of X_Δ and ρ for the previous case are given in the last two columns.

TABLE 4

R_A	R	X_Δ	ρ	X_Δ	ρ
50	5	2.98	59.60	3.00	60.00
500	50	4.12	8.24	9.47	18.94
1000	100	5.10	5.10	13.40	13.40

The scheme employing mututal inductance is seen to be superior for the higher values of resistance but is not as advantageous when

R_A is small since the introduction of 400 ohms at R_1 is objectionable in such cases. When a capacity is used at Z_1 it must be shunted by a high impedance choke in order to allow the flow of the direct component of the plate current.

When both inductance and capacity are used in the amplifier circuits there is a tendency for the system to break into oscillation if the feed back is increased too far. However, by proper manipulation the oscillatory condition may be avoided and satisfactory results obtained.

SUMMARY

There have been discussed several schemes for the alteration of the effective resistance, inductance and capacity of a circuit employing a resistance coupled amplifier. It has been shown to be possible to multiply the reactance of a circuit by a large factor which may be made either positive or negative. Thus it is possible to neutralize the reactance of a circuit for all frequencies. Certain schemes are well adapted to the reduction of resistance and as such may be divided into two classes: (1) those which are independent of frequency, suitable for the reduction of large resistances to a relatively small value; (2) those which are fairly insensitive to small frequency changes and are suitable for the annulment of small resistances.

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A PHOTOELECTRIC PROCESS OF HALFTONE NEGATIVE MAKING APPLICABLE OVER TELEPHONE LINES

By Herbert E. Ives

The method of halftone negative making which is the subject of this paper is a by-product of work on the electrical transmission of pictures, which has been described elsewhere.[1] It uses as its essential apparatus the sending and receiving machines of the telephone picture transmission equipment. It differs from the methods now employed in making negatives for halftone engraving in that the negative produced is accurate in its tone values. This accuracy it owes to the proportionality of response to illumination in the photoelectric cell at the sending end, and to the proportionality of the light valve opening at the receiving end to the photoelectric current actuating it.

In order to understand the merits of the new method it is necessary to review briefly the problem of typographic halftone printing, and the methods heretofore employed in its solution. A typographic printing plate which shall reproduce all gradations of light and shade from white to black must of necessity produce intermediate shades by structures all in the same plane, but of various sizes. In the first commercially practical halftone process[2] a white plaster of Paris cast of a bichromated gelatine photographic relief was pressed against an inked elastic stippled surface. The minute pyramidal elements of the stippled surface were flattened more or less, depending on the depth of the relief and so left dots of various sizes on the white plaster. The latter was then photographed and reproduced by the "line" photoengraving process. In the halftone process, as later developed and now in general use, the production of the lines or dots of varying size but constant density, is done by the action of light through a screen or grating of opaque and transparent spaces, separated from the sensitive plate a sufficient distance so that each aperture of the screen produces an out-of-focus image grading in intensity from center to edge. This graded image acting upon a sensitive emulsion of very high contrast, produces sharply defined lines or dots whose size varies with the intensity of the

[1] "Transmission of Pictures over Telephone Lines," Bell System Technical Journal, April 1925. "Some Photographic Problems Encountered in the Transmission of Pictures by Electricity," J.O.S.A. & R.S.I., *12*, p. 173; 1926.

[2] Frederic E. Ives, 1878.

light or exposure. Prints upon metal from negatives so produced give, after etching, typographic printing plates in which the lines or dots are, as required, all in the same plane but of different areas.

The sizes of the lines or dots which are produced by light acting through a halftone screen are dependent upon a complicated relationship between the characteristic of the photographic emulsion and the character of the dot image as affected by screen distance and lens aperture. As I have shown in a recent paper,[3] the screen process of halftone negative making does not result in faithful rendering of the tones, unless a special procedure, involving extra intermediate processes, is used, or recourse is had, as is done in the practical working of the

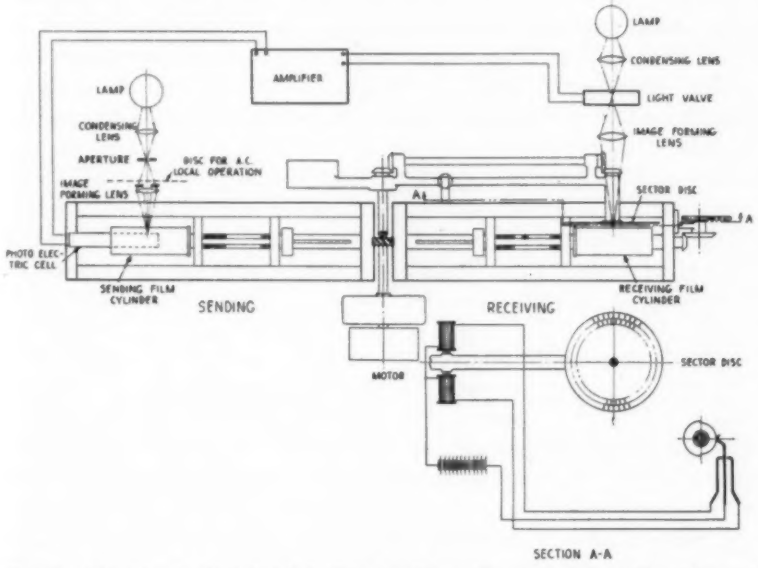

FIG. 1. *Apparatus for photoelectric halftone negative making as arranged with sending and receiving elements on one base, for purely local operation.*

process, to multiple exposures with different diaphragms in the lens. The difficulty may be stated briefly to be that the size of the dot in the halftone negative is not directly proportional to the light intensity.

In the method of structured negative making which is about to be described the dots are not produced by the spreading of photographic

[3] "Tone Reproduction in the Halftone Photoengraving Process," J.O.S.A. & R.S.I., *13*, p. 537; 1926.

action with exposure in an out-of-focus image, but by the formation of a sharply focussed image of an aperture whose size varies with the tone of the picture. It is thus not dependent on the character of the photographic emulsion used; the tone value of a picture so produced is governed entirely by the relation of the aperture size to the light received from the original picture.[4]

The apparatus used in developing the new halftone negative making method consisted of parts of the terminal equipment of the first apparatus used for long distance telephone transmission of pictures. Since that has been fully described previously,[1] only an outline description is here necessary. For purposes of easier exposition the apparatus is sketched in Fig. 1 with both sending and receiving ends upon the same base, the figure showing in fact how the apparatus would be built for purely local sending and receiving, as in a photo-engraving plant. The essential parts of the apparatus are, first of all, a photoelectric cell (at left) upon which a narrow beam of light, passing

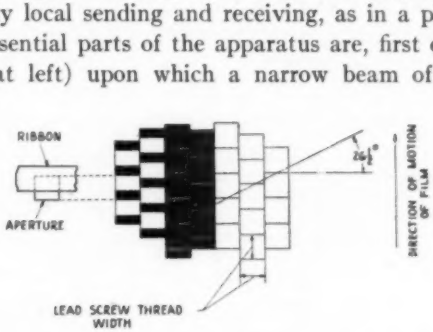

FIG. 2. *Method for producing a halftone structure of small rectangles.*

through a photographic transparency positive produces an electric current proportional to the light intensity. The photoelectric current, after amplification by vacuum tube amplifiers, passes either directly, or over a long transmission line, to a "light valve" which consists of a metal ribbon standing in front of an aperture in a magnetic field. According to the strength of the current passing through the ribbon it is deflected to one side, thus exposing the aperture. The optical system at the receiving end consists of a lens which forms an image of the light valve aperture directly upon the receiving end sensitive surface. For purposes of scanning an entire picture, the original positive and

[4] The use of the light valve to control the amount of light passing through an out-of-focus aperture, or an aperture with shaded edges, was given consideration, but dismissed as unsatisfactory in the light of the previous study of tone rendering by the screen process (reference 3).

the sensitive surface at the receiving end are placed upon cylinders which are rotated and advanced by a screw motion. If the light valve is so oriented that the direction of opening of the valve is at right angles to the lines traced upon the receiving film by the motion of the cylinder, the resultant picture is a line of varying width, similar therefore in texture to the first forms of photo-engraving.[5] In pictures made in this way, however, as has already been pointed out, the relationship between the transmission of the sending end film and the line width is exactly linear, thus being unlike the lines produced by spreading of light through a grating.

The production of halftone negatives in which the structure consists of lines of varying width is a complete solution of the problem of faithful halftone negative making, provided the line structure is not offensive or impractical from a printing standpoint. Experience has shown however that a structure of *dots* is much to be preferred to one of lines from considerations of appearance and typographic printing. One of the principal problems in the present development was therefore to devise means for breaking up the picture into dots, at the same time preserving the exact linear relation which the photoelectric cell, in combination with the light valve, makes possible. The method for intro-introducing the dot which was selected is an optical one, namely the interposition between the light valve and the sensitive receiving surface of a sector disc which interrupts the light in a periodic manner, thus giving a series of separate exposures of the light valve opening. The choice of the shape of the light valve opening and the control of the speed of the sector disc in order that the pattern might be regular constitute the essentially new factors in this work as distinguished from the general problem of picture transmission.

Had the only problem considered been that of producing a photoelectric sending apparatus and a light valve receiving apparatus for *local* use the problem would have been relatively simple, because direct current could have been used for the transmission and the motion of the light valve ribbon would have been continuous. Having in mind, however, the desirability of using this method of halftone negative making over long distances, and in particular, of utilizing the picture transmission system now in use over telephone lines, the problem is considerably complicated by the fact that the current transmitted, for practical reasons in connection with telephone trans-

[5] See reference 1 for pictures made substantially in this way.

mission, is an alternating current of relatively high frequency (carrier current). An immediate complication is produced by this fact in that the breaking up of the received picture into dots by the sector disc method results in the production of moiré or patterns, due to beats between the dot frequency and the transmission frequency, the latter being fixed by transmission line requirements. In order to avoid this, it is necessary to transform the alternating current as received, into direct current, by means of a rectifier, and to filter out the high transmission frequency. The first step taken by way of modifying the regular picture transmission receiving apparatus, was therefore the introduction, at the receiving end, of an electrical rectifier-filter system. By its means the current delivered to the light valve becomes in effect a reproduction of that delivered from the photoelectric cell.

The next question which arises is as to the form of the dot which is to be produced. The simplest form of all is a small rectangle, which

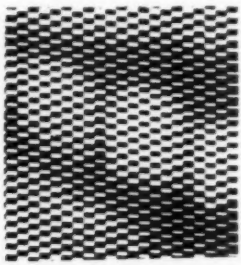

FIG. 3. *Photomicrograph of halftone picture formed by small rectangular structure.*

may be produced by orienting the light valve so that the ribbon lies in the horizontal plane and thus produces with the aperture a rectangular opening which varies from a thin line, at right angles to the direction of motion of the picture cylinder, up to a square. If the spacing of the apertures in the sector disc and its speed of rotation are arranged so that the small rectangular images are displaced by half their width at each successive rotation of the receiving cylinder a very presentable halftone structure is produced, as is shown diagrammatically in Fig. 2 and by the photo-micrograph, Fig. 3. This structure is, however, found to be an undesirable one from the standpoint of typographic printing. It is necessary in a halftone printing plate to preserve a dot structure in the high-lights or whites in order that the inking rolls and later the paper shall not press down into the blank places which would

correspond to a clear white. The small rectangular structure which is under discussion, cannot, it is found, be reduced to nearly as small dimensions as can a dot, so that the high-lights of the picture are altogether too dark when a good printing structure is left. This is particularly the case where the actual printing is done from a stereotype copy of the original plate. Attention was therefore turned to means for producing a square dot of varying size instead of a rectangle of varying breadth.

In order to produce a square of varying size the light valve ribbon had mounted upon it a small tab with a 90° "V" notch cut in its side, and one side of the valve aperture was provided with a similar notch as shown in Fig. 4.[6] As the ribbon of the light valve moves, these

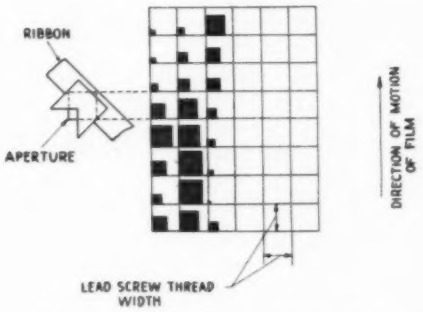

FIG. 4. *Method of producing halftone structure of square dots.*

notches, when placed accurately opposite each other, produce a square aperture of varying size. This square shape is, however, produced at the cost of the linear relationship desired for accurate tone reproduction because the opening is as the square of the current, thus introducing an additional problem.

To offset the squared relationship inherent in this type of aperture, it is necessary to introduce somewhere in the system some electrical element whose response is proportional to the square root of the current. Vacuum tube arrangements having a square root characteristic have been developed for other purposes.[7] If the apparatus were built in its

[6] It is obvious that the dot so produced does not lie at the center of the space exposed by the passage of the sector disc. This could be arranged by the use of a pair of ribbons with a tab upon each, but this refinement is of no practical advantage.

[7] One due to Mr. P. Crisson of the American Telephone & Telegraph Co. will be described elsewhere.

simplest form, namely without the interposition of the transmission line, such a special device to introduce this square root relation would have to be introduced. However, it happens that the electrical rectifier used, as above described, in combination with a filter to eliminate the carrier frequency at the receiving end, has, for certain settings of its "C" battery, a curved characteristic. Instead therefore, of using the rectifier on a straight portion of its characteristic as would be done in using the rectangular openings as shown in Fig. 3, the rectifier setting is made so that a curved portion of its characteristic is used; and very fortunately this curvature is quite accurately of the square root form. It is, therefore, possible, as shown in Fig. 5, to obtain an overall characteristic which is very satisfactorily linear.

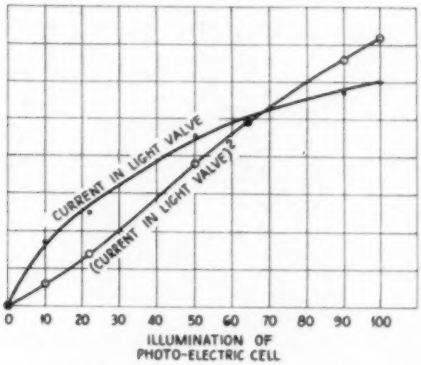

FIG. 5. *Overall characteristic of electrical system used on curved portion of rectifier characteristic.*

It is possible, by having the light valve ribbon either horizontal or vertical, or at an angle of 45°, to produce, in combination with the sector disc, several different kinds of structure. For instance, with the ribbon standing at 45° the dots, which are square, can stand with their sides parallel and at right angles to the threads of the lead screw, which is the direction of motion of the film. This results in a picture in which the dots are lined up with the sides of the picture, that is, without stagger, and in which the number of lines to the inch is, of course, that of the lead screw. In the case of the picture transmission apparatus now in use, this means 100 lines to the inch. This is the scheme illustrated by Fig. 4. If viewed at such a distance that the structure is invisible this kind of picture is entirely satisfactory. At shorter distances, however, the lining up of the dots with the sides of the picture

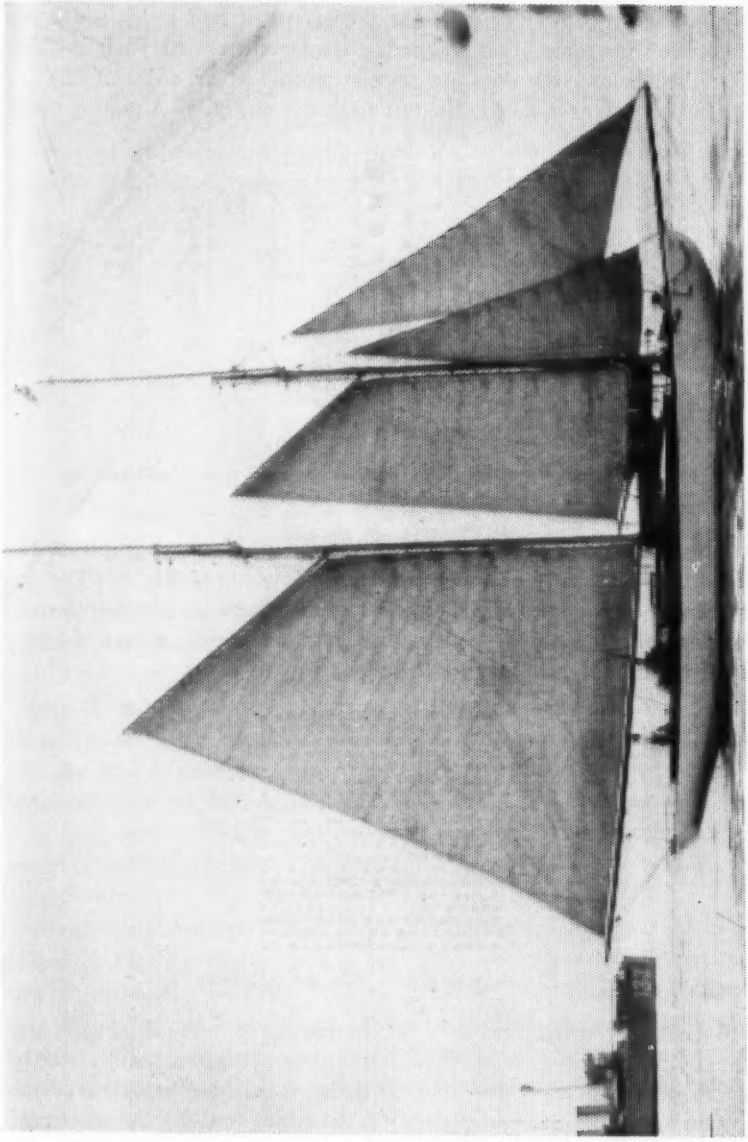

FIG. 7. *Halftone picture made with square dot structure of type shown in Fig. 6.*

is not pleasing. This defect may be largely overcome if the sector disc is run slightly slower or faster to the extent of half a dot width per revolution (or some other staggering arrangement used, such as those described below) the dots are then staggered at an angle of $26\frac{1}{2}°$ to the horizontal, as is shown diagrammatically in Fig. 6. A picture made

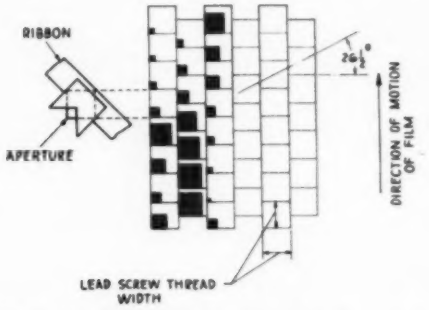

FIG. 6. *Method of producing halftone structure of small squares, with each row displaced a half dot distance.*

in this manner is shown in Fig. 7, and a photo-micrograph of the structure as actually obtained practically is given in Fig. 8. The dot spacing at right angles to the direction of motion of the film corresponds to the lead screw thread width. In the two other directions of lining up of the dots it is 1.12 times this.

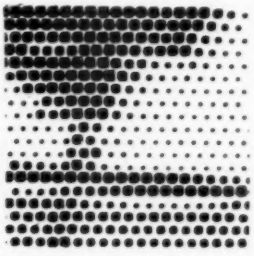

FIG. 8. *Photo-micrograph of halftone picture shown in Fig. 7.*

By having the light valve ribbon horizontal or vertical, square dots oriented at 45° are produced; which is the orientation familiar in the commercial halftone. In order to make these completely cover the picture area without overlapping, it is necessary to make the maximum dot diagonal dimension twice the lead screw thread spacing, drive the

sector disc at half the speed used in the other arrangement, and stagger the dots at exactly 45°, as shown in Fig. 9. By this method of dot production it results that the number of lines per inch when measured at 45°, which is the ordinary method in halftone practice, is $1/\sqrt{2}$ times that of the lead screw. Thus with a 100 to the inch lead screw, the dot picture produced is approximately 70 lines to the inch. This is a very practical advantage in the case of long distance transmission, using the transmission apparatus now in operation, for the reason that

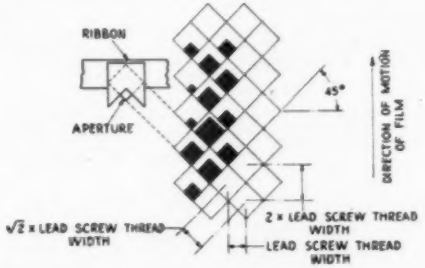

FIG. 9. *Method of producing halftone structure of small squares similar in arrangement to ordinary screen made halftone.*

this is all on a 100 line to the inch basis, which produces very satisfactory variable density pictures. It is, however, desirable that the halftone reception should be on a basis of approximately 65 lines to the inch if the pictures are to be directly available for newspaper purposes. Where the method of dot structure shown in Figs. 2 and 4 is used, this magnification of the structure necessitates the use of a larger diameter cylinder and coarser lead screw at the receiving end. Using the 45° orientation of the dot, as just described, the same 100 thread to the inch lead screw used at both sending and receiving end makes it possible to receive halftone pictures of very nearly the commercial size of structure.

A sample picture produced by the method of dot formation illustrated in Fig. 9 is shown in Fig. 10. By casual inspection it appears like an ordinary "halftone." It has however been produced without any "flashing" or other more or less empirical exposure correction process. On microscopic examination, the dots appear not round, as on the usual halftone, but substantially square, as shown in the photomicrograph, Fig. 11.

FIG. 10. *Halftone picture produced by the method shown in Fig. 9.*

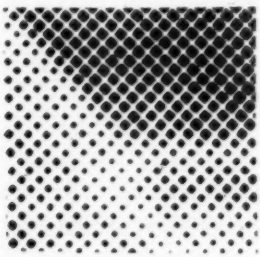

FIG. 11. *Photo-micrograph of halftone picture made as shown in Fig. 9.*

As has been pointed out in previous papers, the reception of the pictures in the form of lines of varying width can be done either in a negative or positive way (sending is *always* from a positive) depending on the initial position of the light valve ribbon. This same possibility holds for the variable size rectangle structure shown in Fig. 2. With the square dot structure, however, this is not the case, because the dot and its complementary spaces are not similar in shape. If the picture is received as a negative, the printing plate made from it will consist of square depressions, with a network of narrow raised lines between them, constituting a very poor printing surface. It therefore becomes necessary in this method, to receive the picture as a positive. This introduces an additional operation which may be either one of photographic reversal or photographic printing.

An important mechanical feature of this method of halftone negative making is the means for producing the proper lining up of the dots or the stagger. This can be done theoretically, by having the speed of the sector disc such that it gains or loses a half dot diameter or diagonal (dependent on the orientation of the dot) with each revolution. This could conceivably be arranged by gears from the main driving motor of the apparatus. Actually gears into which such a small difference in teeth number can be introduced are not commercially available. A friction drive employing friction discs of different sizes was used in a great deal of this experimental work. This, however, proved unreliable and would be impractical for a commercial machine. It is comparatively easy to drive the disc so that the dots line up at right angles to the direction of the cylinder motion. This can be done by any simple gear system turning the disc over an integral number of times for each revolution of the cylinder. It is possible to introduce the stagger by turning the picture at 45° to the direction of development of the lines of dots. This is, of course, very wasteful of space on the machine and is not to be considered seriously. A mechanical method which is practical with accurate mechanical work is illustrated in Fig. 1. This consists in using a disc in which are two sets of apertures, at different radial distances, one set displaced from the other by half the angular spacing between apertures. If the spot of light falling upon the film passes through one of these series of openings during one revolution of the cylinder and then the whole disc is lifted for the next rotation of the cylinder so that the beam of light passes through the other set of openings, the desired staggering is produced. In order to operate this, a cam system is necessary which shall operate in the opposite direction

at each revolution. In Fig. 1 such a cam is shown in the lower right-hand corner. It controls a pair of magnets which act on the arm carrying the sector disc.

The apparatus, as developed, and as here described, has been dominated by the requirement that it should be possible to send pictures from a distant station over a telephone line in exactly the manner they are sent for the ordinary, variable density method of reception, but receive them in a form suitable for halftone printing plate production. If this is not the case; if the production of an entirely local halftone negative making apparatus is all that is desired, certain simplifications may be introduced. The necessity for synchronizing apparatus, such as is used in the telephone picture transmission apparatus to insure the two ends running at exactly the same rate, is removed by the possibility already assumed, in Fig. 1, of mounting both sending and receiving ends upon one track. As already pointed out, direct current from the photoelectric cell end could be used. This, however, is not the only, nor indeed the best possibility. For the most stable electrical conditions, and light valve operation, it would be preferable to use alternating current, not however of the high frequency necessary for telephone line transmission. Instead the photoelectric cell could be exposed by a sector disc of the same aperture spacing as that at the receiving end, driven by the same motor, in exact synchronism with it, as indicated by the dashed line in the sending optical system of Fig. 1. The position of the disc in the optical system, and the size of its openings, should be such that the light exposure followed closely a sine wave shape. The photoelectric current resulting could then be transmitted through an alternating current amplifier, which is highly stable and efficient. The periodic sine wave motion of the light valve would then be photographed exactly at the peak of its excursion by the receiving end disc. In the apparatus used in these experiments the transmission of a $5'' \times 7''$ picture was on a carrier frequency of 1300 cycles per second. By the method just discussed the alternating current frequency in order to give 50 exposures per inch would be reduced to approximately 300 cycles per second for the same overall transmission time.

For this local apparatus a very simple staggering device could be constructed by inserting in the path of the light beam a thick plate of glass which is tilted about a horizontal axis at each revolution of the cylinder, as illustrated in Fig. 12. Such a glass plate should be inserted at both sending and receiving ends if the picture is not to be shifted

between each line of dots, which would result in impaired definition. This latter consideration stands in the way of using this particularly simple staggering scheme in reception from a distant sending machine which may also be sending to apparatus not receiving the picture in dot form.

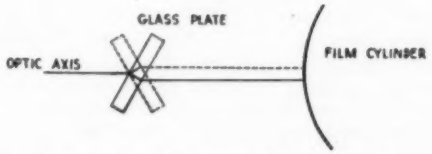

FIG. 12. *Tilting glass plate for introducing a shift of dot position at successive rotations of the film cylinder.*

A point with regard to purely local apparatus is that if the transmission line is eliminated there is no obstacle to greatly increasing the speed of operation, so that in place of the seven minutes transmission time for a 5″×7″ picture as now fixed by the frequency band width of the telephone line speech channels ordinarily used for picture transmission, purely local apparatus should be capable of making a picture of this size in a minute or less.

The description of this photoelectric method of structured negative making may be concluded with some discussion of its fields of usefulness. First of all, considered as an alternative form of picture reception over long distance telephone lines, this process would make it possible to eliminate the operation of halftone negative making by the screen process, now necessary to bring the transmitted picture to the printed page. Thereby a considerable part of the time now consumed between the taking of the original picture and its reproduction in its final form would be saved. Considered next as a process for producing halftone negatives it should have great merit wherever accurate tone rendering is of importance. This is the case in three color work, where lack of linearity in the primary color records will cause distorted color values. It must however, be pointed out, that in order to realize the advantages of this new method it must be supplemented by a process for producing the printing plate which shall accurately reproduce the negative structure.[8]

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[8] A stereotype copy of a bichromated gelatine relief print as used in making the first halftone plates (reference 2) would probably be superior to an etched plate for this purpose. Attention may be called to the fact that figures 7 and 10 have lost some of their characteristic dot shape in reproduction, largely through the etching process employed in making the printing plates.

SOME PROPERTIES OF A HOT WIRE MICROPHONE

By Orin Tugman

ABSTRACT

The temperature of an electrically heated fine wire in the neck of a Helmholtz resonator is reduced by the periodic motion of the air particles. The resulting resistance change, measured by a potentiometer circuit, depends on the heating current, size of opening and position of the wire with respect to the slit. If the wire is below the slit the temperature of the wire may be increased. This indicates the presence of a velocity node a short distance below the opening.

An electrically heated fine platinum wire placed in the neck of a Helmholtz resonator has been used by Tucker and Paris[1] in the construction of an instrument for measuring the intensity of sound. The fine wire is looped several times across a small opening in a mica disk. The periodic motion of the air past the wire causes a constant decrease in resistance along with a periodic change of resistance having the frequency of the sound wave and also a periodic change of resistance having twice the frequency of the sound wave. Another application of the hot wire has been demonstrated by Frieze and Waetzmann.[2] They placed the wire at a point of maximum pressure change in a stationary wave in a tube excited to resonance. Here the periodic change of resistance gave a measure of the temperature changes at a velocity node.

The size of the opening in which the wire is placed and the position of the wire above or below the opening have a marked bearing on the sensitiveness of the apparatus as a sound detector, as will be described in this paper.

APPARATUS AND METHOD OF MEASUREMENT

The platinum wire used in this experiment was made by the Wollaston process or by cutting narrow strips from platinum foil 2 microns thick backed by a heavier sheet of copper. An improvised microtome made of a micrometer screw and a photograph trimmer served to cut strips 0.001 inch wide. The wire was mounted horizontally in a slit of adjustable width edged with mica, on a resonance chamber made adjustable in length with telescoping brass tubing as shown in Fig. 1. A horizontal section through the hard rubber ring A is shown in Fig. 2. The platinum wire is supported and held in the slit by being soldered at

[1] W. S. Tucker and E. T. Paris. Roy. Soc. Phil. Tran., March, 1921.

[2] J. Frieze and E. Waetzmann. ZS. f. Physik, *34*, pp. 131–134; 1925.

its two ends to two vertical pieces of fine steel wire B, B about two inches long which are in turn attached to the brass strips C, C. These strips may be bent by the adjustment screws D, D and so the tension of the platinum wire may be regulated. The platinum wire was soldered to its steel supports with the silver cover or copper backing still on, this being then removed by using the adjustment screws to bow the platinum wire

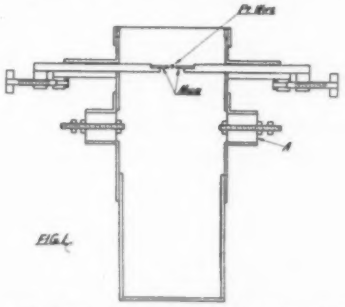

FIG. 1. *Vertical section of hot wire microphone.*

out of the mica slit and dipping the wire in acid. This simplified the handling of the delicate platinum wire and gave good end contacts. The electrical connection to other apparatus was through the contacts E, E.

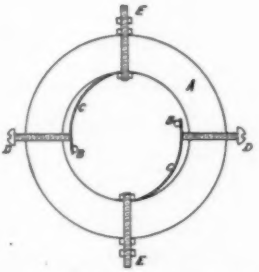

FIG. 2. *Horizontal section of microphone.*

The resistance of the hot wire was measured by a potentiometer circuit as shown in Fig. 3. Usually the potential difference in the wire was beyond the range of the potentiometer. By placing a battery of cells in the galvanometer circuit as shown a balance could be obtained. In this circuit it is desirable to have a large resistance, R_2, in series with the hot wire so that change of resistance of the hot wire, due to sound will not permit appreciable changes in the heating current. However, the voltage changes on the wire due to the sound were multiplied by the factor

$(R_1+R_2)/R_2$ to get the voltage change which would have been measured if the heating current had remained constant.

The apparatus was arranged as described on a table with the slit in a horizontal plane. A piece of fine silk fabric was stretched over the

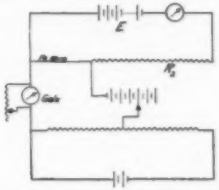

FIG. 3. *Diagram of potentiometer circuit.*

top of the resonator above the wire to prevent any disturbances by stray air currents. The source of sound was a bank of organ pipes several feet away. During any series of measurements the position of the operator and all other objects in the room remained fixed. The heating current was on for at least thirty minutes before any measurements were made. After balancing the potentiometer circuit an organ pipe was sounded and the circuit balanced. Maximum response of the

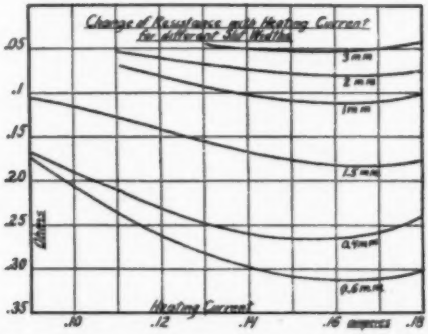

FIG. 4. *Resistance change of microphone as a function of heating current, for various widths of slit, with a constant source of sound intensity.*

apparatus, to sound of any given frequency, was obtained by placing the wire in the plane of the slit and adjusting the width of the slit and the telescoping brass tubing of the resonator. With sound of constant frequency and constant volume of the resonator the effect of sound on the resistance of the wire was measured through a range of heating currents, slit widths, and positions of the wire with respect to the slit.

RESULTS AND DISCUSSION

Fig. 4 shows the change of resistance plotted against heating current for different slit widths when the sound came from an organ pipe having a frequency about 256 cycles per second. It is seen that the sensitiveness of this wire reaches a maximum for a certain heating current and also the maximum sensitiveness is a maximum for a slit about 0.6 mm wide. This effect was found in all samples of Wollaston wire or platinum strip.

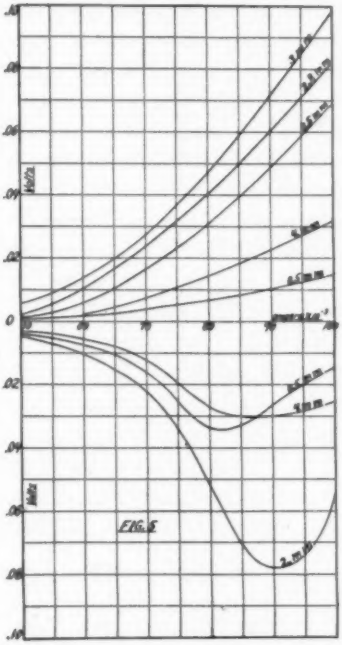

FIG. 5. *Sensitivity of microphone as a function of heating current, for various positions of wire with respect to slit.*

The top of the resonance chamber was arranged so the slit could be raised or lowered, and so the wire could be placed above or below the slit. As the change of resistance is negative when the wire is in or above the slit and positive when the wire is below the slit, negative changes of resistance are plotted below the axis of heating current in Fig. 5, which shows the results of such measurements for different slit widths. Here changes of voltage in the hot wire are plotted against heating currents. It is seen that the maximum increase of voltage occurs at about 3 mm

below the slit. The wire used here is not the same as the one used for Fig. 4.

It is easy to explain the reduction in temperature of the hot wire when it is in the plane of the slit by ascribing the cooling to the periodic motion of the air in the neck of Helmholz resonator. No attempt is made in this paper to explain the increase in temperature due to sound when the wire is below the slit. A similar phenomenon is observed when a fine wire mounted on a movable frame is in a long glass tube excited to resonance by a vibrating loud speaker diaphragm. When this wire is at a velocity loop a decrease in resistance may be observed and an increase in resistance is found when the wire is at a velocity node. As this paper is written to describe the properties of an instrument and not to expound a theory the bearing of these experimental results on the theory of the Helmholz resonator is left for a subsequent paper.

In the foregoing experiments the intensity of the sound was constant, or nearly so, during any series of measurements. To get a variable sound intensity the diaphragm of a calibrated telephone receiver was placed over the top of the resonance chamber. After facing the hard rubber cap of the receiver and enlarging the opening the receiver was calibrated by attaching a light wood stylus to the center of the diaphragm and measuring the amplitude under a microscope micrometer as a function of current strength. An alternating current coming through suitable filters and from a vacuum tube oscillator set served to actuate the telephone. Within the range tried the amplitude was directly proportional to the current at any given frequency. A calibration curve drawn from these data was used in later calculations.

Frequency:	128	256	384	512	640	768	1024
Amplitude (microns per milliampere):	0.42	0.43	0.47	0.49	0.65	1.17	0.74

A ring of soft sheet rubber and a ring of lead intervened between the top of the resonator and the telephone to minimize the communication of sound through the solid part of the apparatus.

No adjustments were made to secure maximum response in this part of the manipulation. The width of the slit, volume of resonator and the heating current in the wire were all maintained constant while the telephone diaphragm was operated by the filtered current from the vacuum tube oscillator. These experiments were made to determine how the apparatus would respond to sound of variable intensity with constant frequency.

The intensity of the sound wave at the slit is proportional to the square of the product of frequency and amplitude of the receiver diaphragm when the frequency is constant. The intensities of sounds of different frequencies cannot be compared with this apparatus because the relative amplitudes of the diaphragm for currents of different frequencies are not the same when the diaphragm is vibrating in a closed box as when the receiver is operating in the open air. However the data obtained from several frequencies and plotted on one sheet (Fig. 6) to show that the apparatus will give a readable response to a

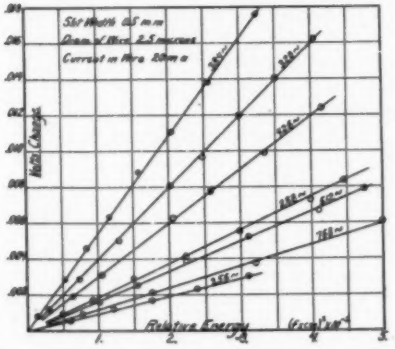

FIG. 6. *Response of microphone as a function of applied sound energy, for various frequencies.*

range of frequencies without changing the slit width or the volume of the resonator. The change in potential on the wire is plotted, instead of the change of resistance, because in this case a resistance sufficiently great was in series with the hot wire, so no appreciable change in heating current was made by the sound.

The linear relation between the change of potential in the wire and the intensity of the sound for any stated frequency is in agreement with the results published by Tucker and Paris. They calibrated their instrument in the open air. The distance between the resonator and the source of sound were measured and the relative intensities calculated by the inverse square law.

SUMMARY

1. The sensitiveness of the hot wire is a maximum for a heating current apparently limited by the construction of the apparatus.

2. The maximum sensitiveness of any given wire is secured by a particular slit width.

3. The change of resistance is a linear function of the intensity of the sound at the slit for any one frequency.

The writer is indebted to Colonel George Fabyan, who provided the facilities for this experiment at the Riverbank Laboratories. Also thanks are due to Dr. Paul Sabine and Dr. Fred Kranz for their assistance in this investigation.

RIVERBANK LABORATORIES
GENEVA, ILLINOIS
FEBRUARY 1, 1927.

Stars and Atoms. By A. S. Eddington, F.R.S., Professor of Astronomy at the University of Cambridge. 127 pages. Yale University Press. New Haven. $2.00.

A non-mathematical discussion of the present status of this fascinating and rapidly developing field based partly on an evening lecture delivered by the author at the Oxford (1926) meeting of the British Association, and partly on three lectures delivered at King's College, London. The headings of the three chapters: "The Interiors of Stars," "Some Recent Investigations" and "The Age of the Stars" are self explanatory as to the scope of the book. Each subdivision is teeming with interest, viz: "Temperature of the Interior of a Star;" "Dense Stars;" "The Story of Algol;" "Unknown Atoms and Interpretation of Spectra;" "Sum-atomic Energy;" "Radiation of Mass," etc.

The reviewer cannot refrain from quoting, verbatim, one paragraph from the section "The Story of the Companion of Sirius," a "detective story" the title of which is "The Nonsensical Message:"

"We learn about the stars by receiving and interpreting the messages which their light brings us. The message of the Companion of Sirius, when it was decoded, ran: 'I am composed of material 3,000 times denser than anything you have ever come across; a ton of my material would be a little nugget that you could put in a match box.' What reply can anyone make to such a message? The reply which most of us made in 1914 was—'Shut up. Don't talk nonsense.' "

And then follows the rest of the story.

If you are not strong minded enough to leave a book alone until you have finished reading it, don't start Eddington's "Stars and Atoms." It is quite irresistible!

F. K. RICHTMYER

A COMPACT COLOR MIXER

By J. M. McGinnis and D. S. Piston

It is well known that the ordinary motor color mixer, using rotating cardboard disks, is unsatisfactory for many experiments because of the difficulty involved in shifting the disks. This machine is so arranged that the combination of colors can be varied without stopping the machine.[1]

This apparatus carries three disks which can be regulated so as to give a mixture of the three colors in any desired proportions. It consists of three concentric hollow shafts, *A*, *B*, *C*, Fig. 1, to which the disks are attached by specially designed clamps. The shafts are made to rotate with respect to each other by the following device.[2] A straight slot is milled lengthwise of shafts *A* and *C*, and a spiral slot is milled

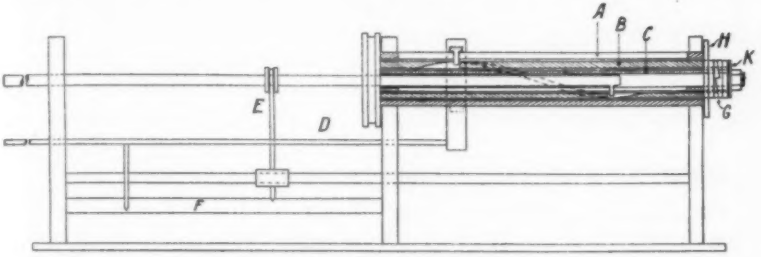

Fig. 1. *Color mixer.*

in shaft *B*. By means of collars two pins, which pass through the straight slots and engage in the spiral slot, can be moved lengthwise of the shaft, thus rotating the shafts *A* and *C* with respect to *B*. By means of arms *D* and *E* reaching out from the collars, the amount the collars move, and hence the sizes of the three sectors, can be indicated on an attached linear scale *F*. These arms also allow the sectors to be adjusted without stopping the rotation of the machine.

[1] There are, of course, other machines of somewhat different construction, which will do this same thing. One made by Zimmermann, and another designed by Twitmeyer and manufactured by C. H. Stoelting Co., Chicago, take only two large disks. A machine designed by Fernberger and Roberts, (University of Pennsylvania) will take three disks; and the Marietta Apparatus Co., Marietta, O., manufactures one that takes two disks, and another that takes six disks.

[2] This spiral head and pin device is that originated by Abney and used by him in his form of variable aperture sector disc.

The mixer is driven by a belt which passes over a pulley on shaft *A*. Using the disks employed on the ordinary color mixer, it is possible to get up to about 355 degrees of any one color; using two specially made disks having angles somewhat greater than 360 degrees[3] it is possible to secure any combination of colors, and still have the disks overlap at any one time.

The 360 degree disk on the center shaft has a smaller hole in it than the other disks, and is held between two rings *G* so made that they hold the two ends of the disk apart just enough to allow the passage of the other two disks. The holes in the other two disks fit over these rings. Each of these disks is attached to its respective shaft at *H* and *K* by a small brass clamp which is attached to a flat spiral of thin spring brass, so that the disks are free to move longitudinally on the shaft while they are being adjusted.

The machine described has the advantages of lightness, compactness, and comparatively low cost of construction. Without the base and motor, it weighs in the neighborhood of ten pounds, and it will fit in a space of 24 by 7 by 3 inches.

DEPARTMENTS OF PHYSICS AND PSYCHOLOGY,
UNIVERSITY OF MAINE
ORONO, MAINE.

[3] Suggested by J. R. Roberts, University of Pennsylvania.

LABORATORY APPARATUS FOR THE ELECTROLYTIC PREPARATION OF OXYGEN AND OF OZONE*

By Oliver R. Wulf†

In the course of some investigations on the kinetics of ozone decomposition[1] there was desired an apparatus for the electrolytic preparation of oxygen from alkaline solution capable of delivering gas at relatively high rates and under conditions such that reasonable purity of the gas would be assured. It was necessary that the gas be collected quantitatively to permit using the current as a measure of the rate of flow, and it was desirable that the oxygen after liberation at the anode should come in contact with only the solution and glass walls.

Since in the electrolysis of alkaline solution the solution is diluted about the anode, concentration polarization is of course an important factor wherever the anode space is small or is partitioned from that of the cathode. An attempt to use an apparatus consisting of a large U of pyrex glass with nickel electrodes and a solution of barium hydroxide met early failure due to such polarization. In this apparatus everything had been sacrificed for purity of the gas. The final apparatus was the result of a compromise.

The cell is shown in Fig. 1. The problem was to stir the electrolyte without admixing the gases, and the glass bell in which the oxygen was collected was so constructed as to permit this. Since in other details the cell is not unusual, only this bell need be described, the figure illustrating sufficiently the general construction. The containing jar was of approximately nine liters capacity. Both electrodes were entirely of sheet nickel, the electrolyte being a 12% solution of pure sodium hydroxide in distilled water. The collar cathode is shown at *C* and the anode at *A*, the glass tube *B* enclosing the latter where it passed down through the electrolyte and up under the bell. The exposed surface of the anode was approximately 40 square centimeters. The top of the cell was covered loosely by plates of glass and by the wooden frame which supported the anode and bell. Carbon dioxide from the air was thus not excluded from the cell.

* Contribution from Gates Chemical Laboratory, California Institute of Technology, No. 138.

† National Research Fellow in Chemistry.

[1] Wulf and Tolman, J. Am. Chem. Soc., *49*, pp. 1183, 1202, 1650; 1927.

The oxygen chamber was a bell of 6 cm thin-wall pyrex tubing, which had four tubes leading out of its side and placed symmetrically around it, each about 4 cm long and of 2 mm inside diameter. These tubes projected downward and outward from the side of the bell. Their ends were at a depth of about 4 cm below the collar cathode, thus well below the cloud of hydrogen bubbles evolved during operation, which never extended much below the lower edge of the collar cathode. The density of the solution tends to increase outside the bell around the cathode and to decrease within the bell around the anode. This, aided by the rising stream of oxygen bubbles within the bell, produces

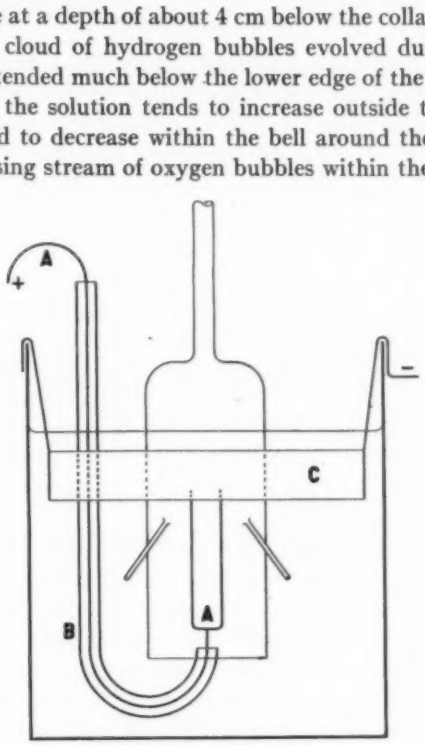

FIG. 1. *Electrolytic oxygen cell.*

a slight stirring from without the bell downward and within the bell upward, the path of stirring completing itself through the small side tubes.

In a suitable light the out-streaming may be seen and in all cases up to 15 amperes it is relatively slow. Observation showed that almost no oxygen escapes through these side tubes, but a very small amount of the most finely divided gas may do so. For most purposes this amount is negligible.

In continuous operation at 15 amperes the cell shows no tendency to polarize. From the start the temperature rises, approaching equili-

brium asymptotically with the surroundings, and in a similar manner the resistance of the cell falls toward a constant value. No other important change appears to occur in its operating characteristics. In a test run made to observe the behavior of the cell, after four hours of continuous operation at 15 amperes it had nearly reached equilibrium with its surroundings at approximately 80°C, room temperature being at 24°C. At the start the resistance of this cell was about 1.4 ohms and at the end of the four hours it was nearly constant at 0.7 ohms. Artificial cooling would not be difficult to carry out, but it was not found necessary in the work in which this cell was used.

The characteristics of this oxygen are mentioned in the papers referred to above. Clearly spray and hydrogen are possible impurities, the latter due to the fact that the oxygen rises through electrolyte which is at least partially saturated with dissolved hydrogen.

In these same researches a convenient form of electrolytic ozone generator[2] was also devised, capable of delivering gas at relatively high rates. It is not different in principle from the familiar form, its simplicity and ease of construction being its only unusual features.

It is somewhat laborious and costly to construct a water-cooled platinum anode of small surface (which is the form of electrode generally used in the production of ozone electrolytically), especially if it is to be used with high total currents. Lead may be used in place of platinum and a convenient form of water-cooled lead anode is the new feature of the apparatus to be described.

The generator illustrated in Fig. 2 was an electrolytic cell contained in a glass jar of about five liters capacity, the electrolyte being dilute sulfuric acid.[2] A lead collar *C* of large diameter served as cathode, suspended by lead arms from the edge of the jar. The anode was contained in a glass guard-tube *B* (which is shown on a slightly larger scale than the other parts of the figure). This tube passed down through the electrolyte and made a full turn, coming up under a glass bell in which the oxygen rose and was collected.

The anode consisted of a small lead cylinder *A* cast around a sharp bend in a piece of small size copper tubing, the tubing being tinned

[2] For information concerning the production of ozone by electrolysis one should consult the work of Fischer and his co-workers, ZS. f. anorg. Chem., *52*, pp. 202, 229; 1907; *61*, pp. 13, 153; 1909. The valuable book by Moeller, *Das Ozon*, Vieweg, 1921, affords a convenient review of the subject. The concentration of ozone produced electrolytically is strongly dependent on the anode cooling, on the current density, and on the concentration of the electrolyte. No attempt was made in this work to obtain the high concentrations which this method is capable of producing.

with solder before casting. During the making of the bend the tubing was repeatedly annealed. The casting of the cylinder was accomplished simply by boring a hole through a block of hard wood of appropriate thickness, setting this on a metal plate, inserting the tinned bend of the tubing vertically to within a few millimeters of the bottom of the hole, and pouring in the molten lead. The double length of copper tubing with the lead cylinder cast about its end was placed in a bench lathe and a small cut taken off the cylinder until this made a slide fit

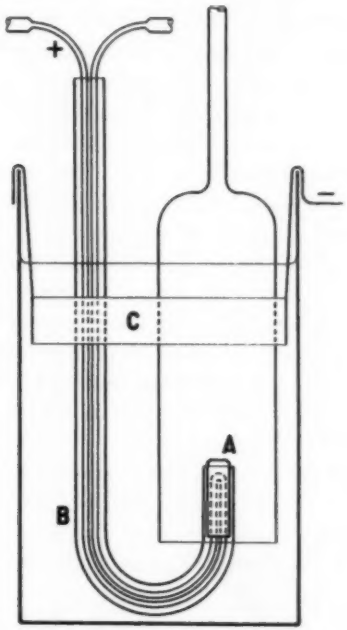

FIG. 2. *Electrolytic ozone cell.*

in a heavy-walled piece of pyrex tubing of about 1 cm inside diameter. This glass tube was bent into the form shown in Fig. 2. The copper tubing and lead cylinder were inserted in it afterward by first starting the free ends of the tubing into the bend, and then by pushing and by pulling also using a wire affixed to the ends of the copper tubing, the anode could be slipped into the position shown in the figure. The glass tube thus served as a guard for the electrical connection to the anode, this connection, the copper tubing, also being connected with a cold-

water supply, thus affording the means of cooling the anode which in an electrolytic ozonizer is of great importance. The anode surface exposed to the electrolyte in the present case was of the order of one square centimeter.

The anode may be used in this fashion, the electrolyte rising in the guard tube to the same level as in the jar. However, rather rapid deterioration of the copper tubing is liable to occur under these conditions, and to avoid this, it is well to fill the entire guard tube up to and around the lead cylinder with paraffin.

Only small heating occurs in the generator during operation, for the resistance is low and there is no important concentration polarization, since the cathode is large and is immersed in the main body of the electrolyte. The surface of the anode is soon covered with a layer of elad dioxide. The anode slowly wears away with continued use. A suspension of lead dioxide accumulates in the electrolyte during each operation, settling slowly afterward.

The generator was used with loads up to 12.5 amperes in the investigations mentioned, 10 amperes being the highest load used commonly for long times. No test was made, however, to determine the heaviest loads that could be used successfully. Concentrations up to 3% by volume of ozone were obtained in this work.[1] The ozone made in this way appears to be nearly free of disturbing impurities, or at least to contain them in a nearly constant amount.

Another form of oxygen generator used may be briefly mentioned. Finding the ozone made by electrolysis of dilute sulfuric acid to be apparently nearly free of impurities, oxygen produced in this same way was also of especial value. But even with a relatively small current density, i.e. with an anode of large surface and with no artificial cooling, the oxygen evolved in sulfuric acid solution contains some ozone. A generator was constructed on the same plan as the electrolytic ozonizer, except that the anode guard-tube enclosed a single length of ¼ inch bore lead tubing, the end emerging from the bend into the electrolyte having been slit lengthwise on one side for several inches and flatened out. This afforded a strip of sheet lead roughly one-inch wide that was shaped into a small cylindrical helical electrode.

The evolved gas, after being passed through the customary air-cooled condenser was passed through a length of pyrex tubing of 4 or 5 mm bore, which had wound upon it an asbestos-covered electric heater of nichrome wire. The heating tube was approximately 30 cm long. From this, before going to the drying system, the gas passed through a

water-cooled condenser to bring the moisture content at least as low as saturation at room temperature. With the tube at a temperature below redness and at a rate of flow corresponding to 5 amperes, the ozone content was reduced to an amount negligible for most purposes, being of the order of 0.02% by volume, leaving oxygen of purity similar to that of the gas produced by the electrolytic ozonizer.

CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIFORNIA.

Selective and normal photoelectric effect of potassium, gas-free and after attack by hydrogen.—In these experiments Fleischer and Dember formed mirrors of repeatedly distilled potassium in a high vacuum (the way in which the optically-smooth surfaces were obtained is not described); measured their absorbing-powers for light of the qualities used (they "measured the optical reflecting-power by a photoelectric photometer-method, such as has often been described"); measured the photoelectric emissions from them; contaminated the mirrors with gas, and repeated the measurements. The gas was applied, in the earlier work, by letting the tube stand for a period of several months (the gas presumably diffused out of the walls or the cements); in the later work, by glowing a filament sealed into the tube and previously charged with hydrogen. The light was incident at 45°, and polarized with the electric vector in the plane of incidence. The optical absorbing-power, plotted vs. wave length, shows for the pure metal a maximum at 313 mμ, which with increasing contamination slides along to 436 mμ. The photoelectric emission per unit incident energy likewise shows a maximum initially at 313 mμ, which slides along to 436mμ and there becomes much more pronounced. The photoelectric emission per unit absorbed energy for the pure metal shows no maximum—so that the maximum in the curve for unit absorbed energy is due exclusively to the maximum in the absorbing power; but for the contaminated metal it shows a strong maximum at 436 mμ, so that the maximum in absorbing-power is not sufficient to account for the effect. Experiments with "black-body" cells—tubes of which the entire internal walls are covered with potassium, so that all the entering light is absorbed—show concordant results; no maximum in the photocurrent-vs-wave length curve for clean potassium, a maximum at 436 mμ for potassium which hydrogen has touched. Observations with the electric vector perpendicular to the plane of incidence show the well-known features; the gas improves the sensitiveness somewhat. [R. Fleischer and H. Dember (Dresden); ZS. f. techn. Phys., *7*, pp. 133–137; 1926. R. Fleischer; Ann. d. Phys. *82*, pp. 75–86; 1927.]

KARL K. DARROW